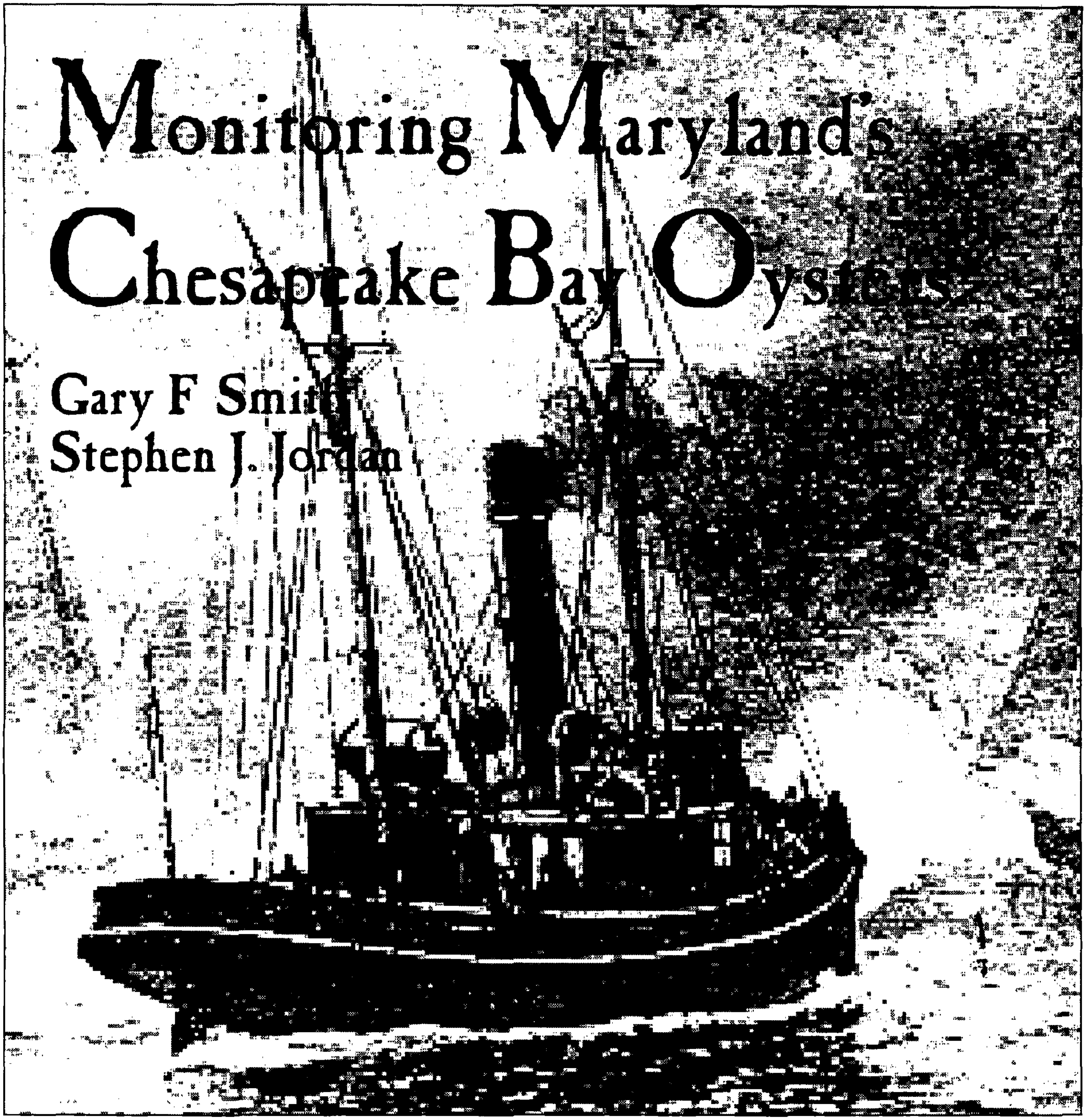
Monitoring Maryland's Chesapeake Bay Oysters

Gary F Smith
Stephen J. Jordan



CHESAPEAKE BAY RESEARCH AND MONITORING DIVISION

CBRM-OX-93-3

As Secretary of the Maryland Department of Natural Resources, I am convinced that public support of DNR's mission is essential if we are to restore the State's once bountiful natural resources, especially the Chesapeake Bay, to the level which earned the title "America in Miniature". The information in this publication is designed to increase your understanding of our program and of Maryland's natural resources.

Torrey C. Brown, M.D.

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MONITORING MARYLAND'S CHESAPEAKE BAY OYSTERS A COMPREHENSIVE CHARACTERIZATION OF MODIFIED FALL SURVEY RESULTS 1990 - 1991

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EXECUTIVE SUMMARY

This report presents two years of results (1990-1991) from a Maryland Chesapeake Bay oyster monitoring program designed to characterize and assess the condition and trends of Maryland's oyster populations. The program was developed as a modification to the Department of Natural Resources, Division of Fisheries, existing Fall Oyster Survey. The purpose of the modifications was to develop a valid long-term oyster monitoring program from an existing survey which was geared to providing qualitative information on a site-specific basis, primarily for specific fishery management needs.

The design of the modified survey is intended to provide annual estimates of Baywide and regional oyster spatfall intensity, mortality, disease, and population size structure. Statistical validity and consistency of data were paramount considerations in the modified design. The aim was to assist oyster management with a reliable and useful representation of the resource, based upon a feasible and cost-effective monitoring program consistent with historical observations.

The survey samples 64 "key", or regionally representative, oyster bars each year. Replicate samples provide information on spatfall, population size structure, mortality, disease, repletion history (i.e., the record of seed and shell placement), and physical characteristics. Data management and analysis are computer-automated, with mostly graphic output. The objective of the data management system is to allow the data to speak to a variety of users. Numerical and statistical analyses are available for specific needs. One objective of this initial report is to stimulate suggestions from potential users as to possible survey modifications, additional analysis to be performed, and report format for future survey results.

The approach of this monitoring program has been to assess the overall condition of the resource Baywide and dynamically over time. The present Maryland oyster fishery is largely concentrated on a relatively few productive oyster bars, compared to Maryland's total oyster producing and growing bottom, upon which this survey concentrates. Although the survey can provide direct answers to some fishery management questions (e.g., spat density and disease prevalence in specific areas are important in the repletion program), it is designed primarily for broad scale assessment of the status of the resource and trends in response to natural and anthropogenic impacts.

Results suggest that parasitic infection by *Perkinsus marinus* (Dermo disease) was the most significant factor affecting mortality and growth in oyster populations between 1990 and 1991. *Haplosporidium nelsoni* (MSX disease), another parasite which recently has been undetected in Maryland waters, also reappeared in 1990 and 1991. Although both diseases have been responsible for oyster mortalities in Maryland waters since at least the 1950's, the current level of *P. marinus* disease is unprecedented.

Perkinsus disease levels at sampling sites correlated well with observed mortalities. In 1990, average estimated annual mortality on survey oyster bars was 17%. In 1991, this increased to 31%. The highest percentage of dying oysters was of a size range just below that of a "market" or harvestable oyster. An additional effect of high *P. marinus* levels was slow growth of affected populations.

These high mortalities were responsible for a noticeable Maryland Baywide decrease in relative oyster abundance between 1990 and 1991. Actual quantification of this decrease is difficult due to the seeding of young oysters on some of the survey oyster bars.

Spatfall relative to historical averages (Krantz 1992) was poor to fair in 1990 and at historical highs in 1991. Areas of highest spatfall were also regions where *P. marinus* disease was at its highest levels. The upper bay regions exhibited noticeably poor spatfall for both years.

Although disease has been identified as a major reason for the lack of marketable oysters, the effects of harvest are also evident. Analysis of the survey oyster bars which were harvested in both years (33% of total survey bars) estimated that 53% of market-sized oysters were removed by harvest during a given year. Seed repletion on many of these harvested oyster bars was vital to their remaining productive.

Note added in proof

During the period when this report was undergoing review and editing, the 1992 Modified Fall Survey was completed. These results will be reported in the annual Population Status Report for 1992, in draft as of March 22, 1993. A few important findings are summarized below.

- *Perkinsus marinus* (Dermo disease) now infects all surveyed oyster bars in Maryland.

- The prevalence (percent of oysters infected) of *P. marinus* is higher than ever recorded in Maryland, from records going back to 1960.

- *Haplosporidium nelsoni* (MSX disease) spread to a large percentage of surveyed oyster bars between 1991 and 1992.

- Oyster mortalities in 1992 were higher than in 1991, reflecting the increased prevalence and geographic distribution of both diseases.

- Mortality of small (sub-market sized) oysters increased, very probably because of *H. nelsoni* infections. This parasite, unlike *P. marinus*, generally kills oysters within the first year of infection.

The management implications of increased disease pressure and mortality will be discussed in the 1992 Population Status Report; however, the losses of both market and seed oysters in 1992 are expected to have severe impacts on the fishery beyond the 1992-1993 season. Management options will be further constrained by high mortalities of seed oysters, and the constriction of areas where oysters can survive to market size in harvestable densities.

ACKNOWLEDGEMENTS

The authors wish to express their gratitude to those whose contributions made the publication of this report possible.

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I. INTRODUCTION

The dramatic decline of the Maryland oyster fishery over the past several years has been a matter of great concern to the industry, responsible government agencies, and the public as a whole. Historically, the Chesapeake Bay had been the largest producer of oysters in the United States. As recently as 1974, the Maryland portion of Chesapeake Bay produced 2,800,000 million bushels of oysters annually. By the mid-1980's, the harvest had declined to approximately 1,000,000 million bushels (R. Scott, MDNR, pers. comm.). By 1990, oyster yield had fallen to 418,000 bushels, and in 1991, 322,000 bushels.

The effect of this decreasing harvest has been most dramatic in historically high producing areas. The Tred Avon River, a small tributary of the Choptank River, produced 124,000 bushels of oysters in 1984. By 1991, harvest was reduced to 750 bushels. Eastern Bay produced 900,000 bushels of oysters in 1973, but only 20,000 bushels in 1991. Only in the Chester River has harvest maintained typically historical levels (~50,000 bushels; 1970's averages), due largely to extensive transfer and placement of oyster spat in this region through the State's Repletion Program. Currently, this area, other northern Bay regions, and upper reaches of some tributaries support the remnant Maryland oyster harvest.

The historically low harvest of the 1991-1992 oyster season has raised questions as to whether the oyster industry in Maryland has a viable economic future. These concerns have not been ignored. Much effort has gone into understanding the causes of this decline, as well as management strategies, stock enhancement methodologies, and research which could turn around the decline.

For any of the above approaches to be successful, reliable information must be available from oyster monitoring programs. Such programs must be consistent from year to year and provide accurate and defensible data.

Maryland historically has collected information on various aspects of its Baywide oyster resource. Generally, these programs have been designed to address specific and immediate management needs. The Maryland Department of Natural Resources, Fisheries Division (and its predecessors) have been collecting oyster bar data from 1939 onward. This annual survey has been referred to as the Fall Survey. Spatfall, mortality, number of oysters, fouling, physical data, and many other variables have been recorded. Although these data have multiple uses, the primary purpose was to provide information to assist decisions about planting cultch (shell) and moving spat.

The Fisheries Division has also collected oyster harvest data based on regional landings. In addition to this harvest data, aerial surveys are periodically made to assess the geographic distribution and effort (boat counts by gear type) of the oyster fishery.

Since the 1960's, oyster disease data have been compiled by the Maryland Department of Natural Resources in cooperation with the National Marine Fisheries Service. The prevalence and intensity of the oyster parasites

Haplosporidium nelsoni (MSX) and *Perkinsus marinus* (Dermo) are the most important aspects of these data.

Modifications to the Fisheries Division Fall Survey were made in 1990 and 1991; these were enhancements rather than a replacement of the existing survey. Historical data sheets are completed as always. The modified design does not deviate from the historical survey in a manner that would not allow direct comparison with historical data. The primary purposes of the modifications were to standardize sampling locations and protocols, and to introduce replicate samples to allow statistical inferences to be made for individual sampling sites.

This report presents results for the two years that the Modified Fall Survey (MFS) has been conducted (1991 and 1992). Although Fall Survey data and oyster disease data have been collected in a standard format from the 1960's onward, comparison with this information is not included within this report. Historical analysis is a project objective, but will require additional verification, calibration, and data base integration. This work is now in progress and will be described in another report.

Results have been organized into four major population components: 1) recruitment; 2) population structure and mortality; 3) disease; 4) harvest implications. The presentation is mostly graphical. This report is not directed toward hypothesis formulation and testing, but rather a descriptive characterization. We hope that this approach will provide a basis for future analysis. Analysis of harvest activity effects is limited to comparisons of the characteristics of harvested oyster bars to those of non-harvested oyster bars—the extent of information that can be recovered from the current survey.

The discussion has two parts. First is the development of an integrated interpretation of the four components of the results. Characteristics of Maryland's oyster populations are briefly reviewed in the context of a traditional population dynamics framework, accompanied by a simple model that attempts to estimate relative fishing mortality and the effects of seed on repopulating harvested oyster bars. The second part of the discussion is a general review of the merits and limitations of the MFS, with recommendations for additional enhancements to this important monitoring program.

II. METHODS

Site Selection

Sixty-four charted oyster bars distributed throughout the Maryland portion of Chesapeake Bay (Figures 1 and 2; Table 1) were chosen to provide geographical coverage of oyster regions of the State. These oyster bars were sampled for population variables consistently from year to year to allow direct yearly comparisons. Samples from a subset of 43 of these oyster bars were analyzed for *P. marinus* and *H. nelsoni*.

Site selection represented a consensus of Cooperative Oxford Laboratory and Fisheries Division personnel, based on the following criteria:

- Full geographical coverage of historical oyster-producing regions in the Maryland Bay, not just current harvest producing areas;

- Greater coverage in Bay regions which historically had been major oyster-producing regions (i.e. oyster bars were not randomly selected Baywide);

- Close correspondence with previously defined "key bars" to maintain consistency with historical spat count data (Krantz 1991);

- Retain oyster bars which had been sampled most frequently in the historical Fall Survey, and those for which the most complete records of disease existed.

Oyster bar latitudes and longitudes shown in Table 1 are those of the uncorrected LORAN C sampling locations on given oyster bars. Because typical oyster bars cover a large area of bottom and vary greatly from point to point in character, sampling was done at the same location on each oyster bar from year to year.

Small inconsistencies between 1990 and 1991 sampling occurred due to oversights in coordination. In 1990, MADP (Manokin River-Drum Point) was omitted from the 64 monitoring sites. Oyster bars selected for the disease subsample also varied from the 42 initially chosen. In 1991, one other oyster bar CRRO (Choptank River-Royston) was analyzed for disease. This additional site is now considered as part of the disease monitoring subset.

These inconsistencies had little or no impact on the results reported here. The majority of comparisons between years are represented as averages. Where summations were used in analysis, aggregrate differences between years greatly outweighed any variation due to single sites.

Sampling Regime

All 1990 samples were collected between October 8 and November 16. In 1991, samples were obtained between October 15 and November 18. The choice of fall for sampling is a compromise among three factors: 1) the spring-summer spat set must grow to a size to be visually identified; 2) *P. marinus* and *H. nelsoni* generally have exerted their effects on the population (mortality) during the preceding summer; 3) although the oyster harvest season begins before the time of sampling, early fall sampling minimizes the effects of harvest, given the other constraints on the survey.

Dredge Sampling Methodology
Oyster dredges had a 3 ft. (91.4cm) wide opening with 12 teeth on the bottom trawl bar. Tooth length varied between 2.5-3.25 in. (6.3-8.3cm). A chain bag constructed of 2 in. (5.1cm) diameter steel rings extended back 20 in. (50.8cm) along the bottom of the trawls. The remainder of the trawl bags were constructed of 1.5 in. (3.8cm) square nylon mesh. A completely filled dredge holds approximately 2.0 bushels of material.

Five independent dredge tows were taken from each of the 64 sites. Tow distance was based on filling the dredge bag with sufficient material to provide a complete sample. From each of these five tows, 0.2 bushels of material was extracted at random. Variables 1-3 below were recorded separately from each of the five samples. Variables 4-6 were recorded from the pooled full sample.

1 Total spat count

2 Measurement of each live oyster to 5mm size classes

3 Measurement of oyster boxes (dead oysters with two shell halves still attached). Each box was categorized by relative time since death: *gaper* (meat still intact); *stage 1* (meat absent—inside of shell with light or absent fouling); *stage 2* (inside of shell with moderate fouling); *stage 3* (inside of shell with heavy fouling).

4 Fouling of the sample (percent) was determined by category (mussels, *Molgula manhattensis*, other). If there was sufficient fouling to affect sample volume significantly, fouling organisms were removed before taking 0.2 bushel subsamples.

5 A history of seed and shell placement on the sampled portion of the oyster bar was recorded by year of activity

6 Site identifications, salinity, temperature, and bottom depth

7 At sites designated for disease samples, 30 or more oysters greater than 50mm in length were selected at random and returned to the Cooperative Oxford Laboratory for disease analysis. The minimum size restriction was due to laboratory processing limitations.

Laboratory Disease Analysis
Diagnosis for *P. marinus* and *H. nelsoni* was conducted at the Cooperative Oxford Laboratory. The standard technique employed for *P. marinus* analysis was rectal thioglycollate culture (Ray 1952). Blood thioglycollate culture was also employed for most sites in 1990 and a small number of sites in 1991.

Analysis for *H. nelsoni* was conducted for selected sites in both 1990 and 1991. Site selection was based on presence of high salinity in areas where resurgence of the disease was expected first to occur. Both blood histocytology and tissue histocytology methods were employed for diagnosis, depending upon site and year.

Laboratory analysis determined individual levels of infection for both *P. marinus* and *H. nelsoni* for 30 oysters from a given oyster bar. Stages ranged from 0 (no infection detected), to 7 (highest infection detectable). Three representive indices were calculated for each oyster bar.

1 Percent prevalence of disease

$$100\left(\frac{I}{N}\right)$$

2 Severity index

$$\frac{D_1+2D_2+3D_3+4D_4+5D_5+6D_6+7D_7}{I}=\frac{\sum_1^7 iD_i}{I}$$

3 Intensity index

$$\frac{D_1+2D_2+3D_3+4D_4+5D_5+6D_6+7D_7}{N}=\frac{\sum_1^7 iD_i}{N}$$

where D_i = number of oysters at a given stage (i = 1-7) infected in the sample; I = number of oysters in the sample having infection (stage 1-7); N = total number of oysters in the sample (30).

Data Entry and Analysis
Data were entered into the computer directly from field sheets (Figure 3). Interactive entry programs prompt the user for study specific data. Data storage, entry, and analysis were primarily in dBase III+ format. All field data sheet information was entered and used in analysis.

Present use of the data entry and analysis system has been for MFS data only. However, our computer sorting and filtering routines allow for entry and analysis of any oyster field data that follow the format of the MFS field sheet. Examples of such supplementary oyster data which could be analyzed are seasonal surveys, response surveys for critical needs, and seed and shell planting analyses. Files and program routines are on hand to identify known oyster bars and seed and shell plantings with correct geographical designations.

Appendix A details data storage file field descriptions and statistical calculations used to generate the summary statistics file.

Table 1. Modified Fall Survey sampling sites. Latitude and longitude are in degrees, minutes, and seconds. Codes are those used for computer storage at the Cooperative Oxford Laboratory. An "X" in the last column indicates that the site is sampled for disease analysis.

Code	Area	Oyster Bar	Latitude	Longitude	Disease Samples
BCDN	Broad Creek	Deep Neck	384417	761433	X
BNMP	Bay Bridge North	Mountain Point	390509	762502	
BNSP		Swan Point	390827	761810	X
CHBR	Chester River	Buoy Rock	385938	761242	X
CHOF		Old Field	390448	760952	X
CRCP	Choptank River	Cooks Point	383909	761725	X
CRLI		Lighthouse	383927	761122	X
CROS		Oyster Shell Point	383518	760001	X
CRRO		Royston[1]	384115	761430	X
CRSH		Sandy Hill	383539	760700	X
CRTW		Tilghman Wharf	384247	761915	X
EBBU	Eastern Bay	Bugby	385255	761320	X
EBHN		Hollicutts Noose	385114	762106	X
EBPI		Parsons Island	385420	761602	X
EBWG		Wild Ground	385339	761900	
FBCI	Fishing Bay	Clay Island	381422	755902	
FBGC		Goose Creek Addition	381702	760130	X
HCEP	Harris Creek	Eagle Point	384345	761824	
HOHO	Holland Straits	Holland Straits	380644	760430	X
HRNO	Honga River	Normans	381519	760815	X
HRWI		Windmill	381659	760932	
LCCA	Little Choptank River	Cason	383159	761421	X
LCRP		Ragged Point	383218	761750	X
MADP	Manokin River	Drum Point[2]	380706	755215	
MAGE		Georges Bar	380727	755124	X
MESR	Mid-Eastern Shore	Stone Rock	383920	762259	X
MRAS	Miles River	Ashcraft	384741	761241	
MRBI		Bruffs Island	385129	761135	X
MRLP		Long Point	384613	761032	X
MRTU		Turtle Back	385119	761421	X
NRMG	Nanticoke River	Middle Ground	381345	755519	
NRWE		Wetipiquin	381959	755315	
NRWS		Wilson Shoal	381735	755518	X
POSH	Poplar Island	Shell Hill	384523	762119	
PRBS	Potomac River	Blue Sow	381404	764215	
PRBW		Black Walnut	381454	764105	
PRCH		Cornfield Harbor	380253	762001	X
PRDC		Dukehart Channel	381315	764451	
PRLC		Lower Cedar Point	381959	765850	X
PRRP		Ragged Point	380922	763633	X
PSGU	Pocomoke Sound	Gunby	375706	754626	
PSMA		Marumsco	375733	754409	X
PXBA	Patuxent River	Back of Island	381914	762739	
PXBI		Broomes Island	382428	763351	X
SMCC	St. Marys River	Chickencock	380723	762613	X
SMPA		Pagan	381130	762635	X
TADM	Tred Avon River	Double Mills	384347	760825	X
TSBC	Tangier Sound	Back Cove	380225	755939	X
TSGR		Great Rock	375706	755506	
TSOW		Old Womans Leg	375747	755823	X
TSPI		Piney Island	380409	755734	X
TSSS		Sharkfin Shoal	381256	755929	X

Code	Area	Oyster Bar	Latitude	Longitude	Disease Samples
TSTE	(Tangier Sound)	Turtle Egg Island	380654	755928	
UBBH	Upper Bay	Brick House	385620	762308	
UBHA	Upper Bay	Hacketts	385859	762500	X
UBTS		Three Sisters (= Coots)	385138	762750	
WRES	Wicomico River	Evans Shoal	381231	755341	
WRMV		Mt. Vernon Wharf	381515	754820	
WSBU	Western Shore	Butler (St. Marys Co. Shore)	380632	761937	X
WSFP		Flag Pond	382606	762609	X
WSHI		Hog Island	381854	762301	X
WSHP		Holland Point	384407	763008	X
WWLA	Wicomico River (west)[3]	Lancaster	381635	764945	X
WWMW		Mills West	382009	765129	X

[1]Not sampled in 1990 for disease.
[2]Not sampled in 1990 for Fall Survey.
[3]Potomac River tributary.

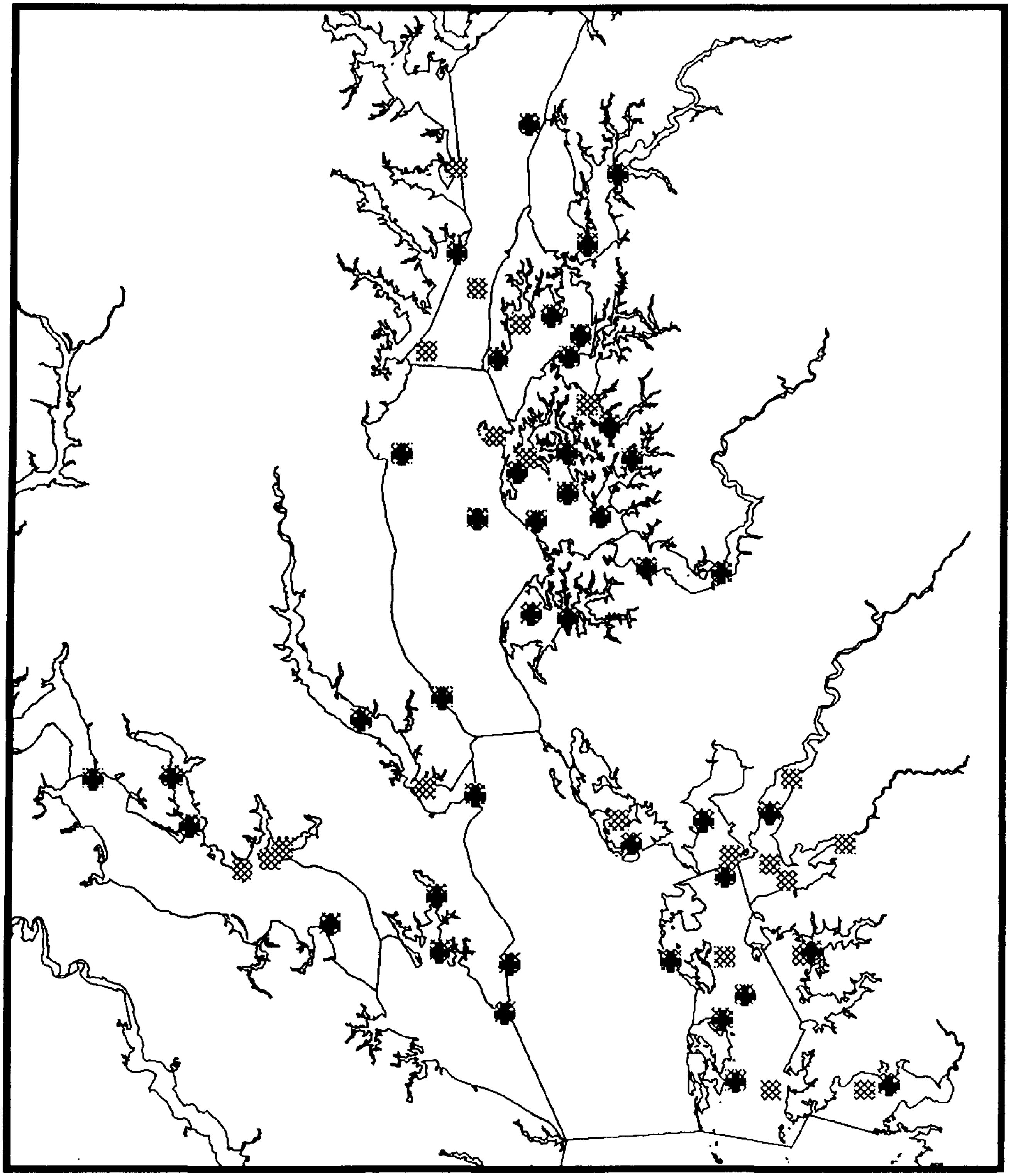

Figure 1. Northern Chesapeake Bay with Modified Fall Survey sampling sites (hatched boxes). The subset of sites monitored for diseases are indicated by bold crosses. Geographical regions used in analysis are separated by lines.

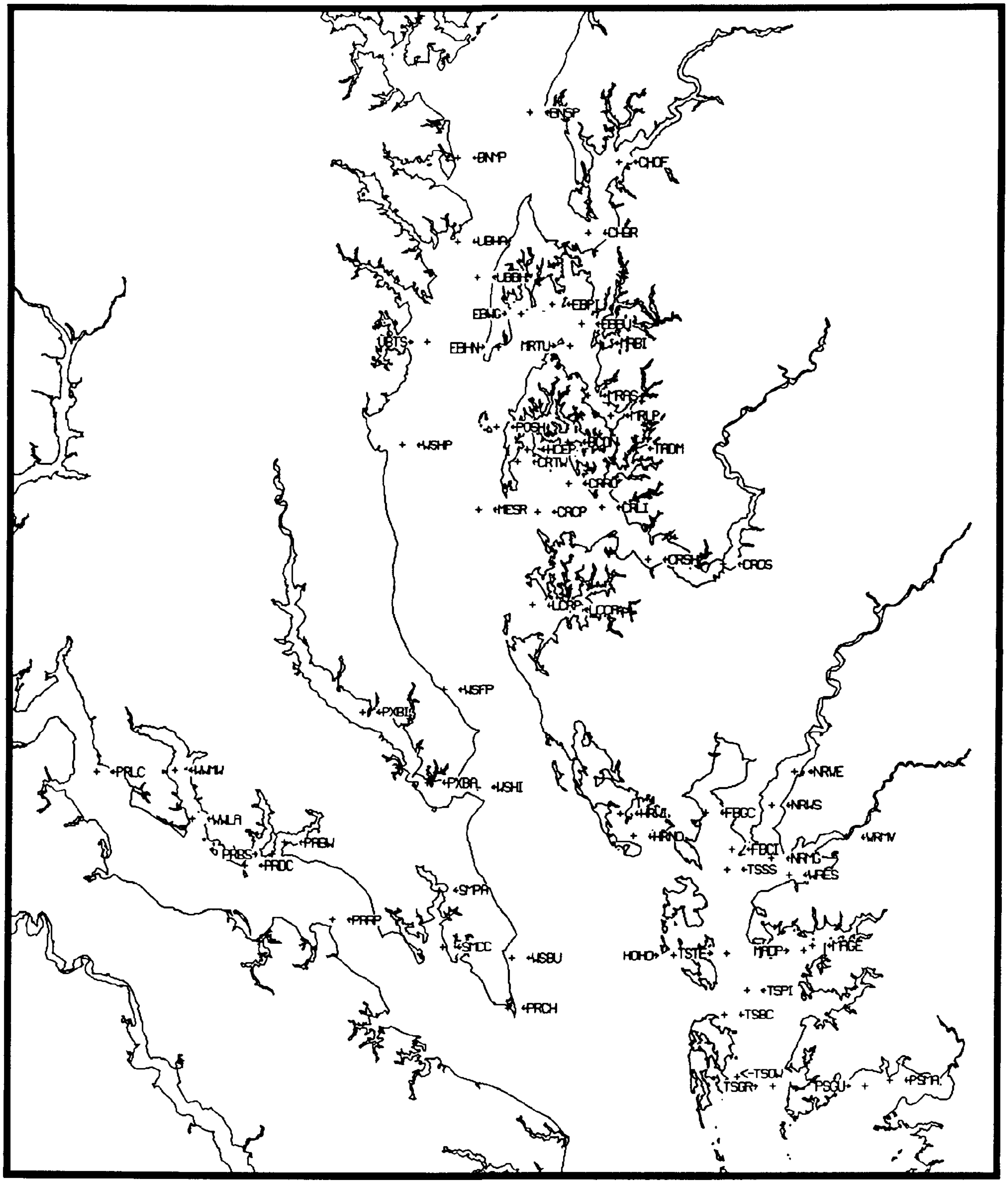

Figure 2. Northern Chesapeake Bay with Modified Fall Survey site codes.

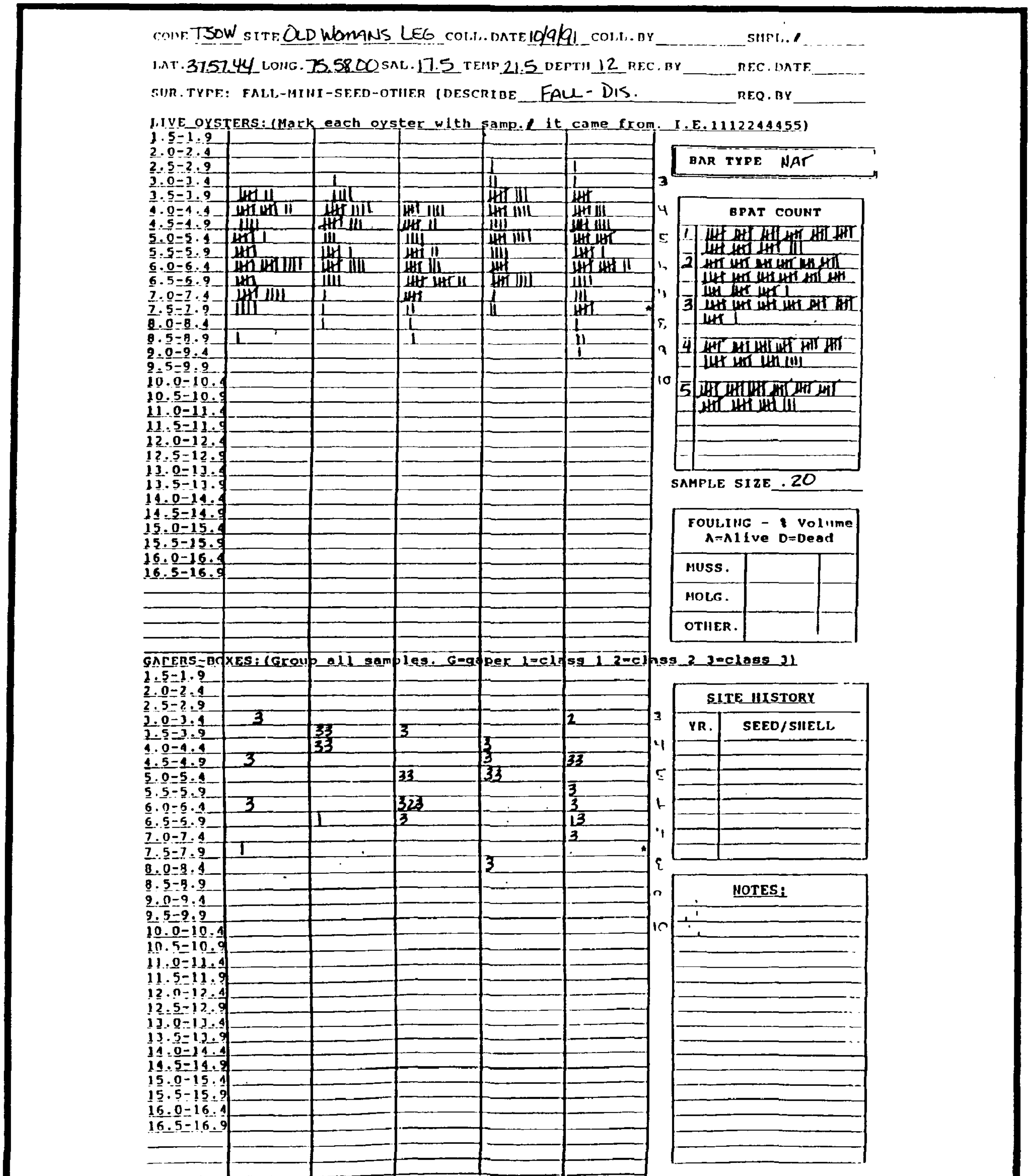

Figure 3. Modified Fall Survey field data sheet, as completed for TSOW in 1991 (reduced).

III. RESULTS

Spatfall and Recruitment to Fishery

Spatfall

Spatfall counts in Maryland Chesapeake Bay waters were very different between 1990 and 1991. The mean spatfall for all MFS sites was 43 per bushel in 1990 and 215 in 1991. In comparison with historical data (1939 to present; see Krantz 1992), the 1990 spatfall was below the long-term average of 55 spat per bushel, whereas the 1991 set was far above average.

Spatfall in both years was highly variable on a bar by bar, as well as on a regional basis. Gross regional trends were, however, very apparent (Figures 4 and 5). Spat counts for individual oyster bars were tabulated in Appendix B.

The 1990 set could be considered good only in the Tangier Sound region, portions of the lower Potomac River, and the Little Choptank River. In 1991, spatfall was excellent in these regions as well as the Choptank River, mid-mainstem of the Bay, and Eastern Bay. In both 1990 and 1991, spatfall was poor or absent in the upper Bay and Chester River regions.

Two-year changes in overall spatfall densities can be examined further as functions of the number of geographic regions falling within six ranges of average spatfall (Figures 6 and 7). Refer to Table 2 for descriptions of the regions and the numbers of monitoring sites in each. Figure 8 shows the geographic locations of these regions. Four non-oyster producing regions were removed from this and later analysis (i.e., Northern Bay Flats, Sassafras River, Northern Bay Neck, upper rivers and upper mainstem). In 1990, the great majority of the Bay's oyster regions produced <20 spat per bushel. Only three regions had >100 spat per bushel. This pattern reversed in 1991, with counts >100 in more than half of the Bay's oyster regions. In 1991, four of Maryland's oyster growing regions produced more than 300 spat per bushel.

Table 2. Maryland Chesapeake Bay oyster bars—geographic regions. Refer to Figure 8 for geographic boundaries. A = number of sites sampled for population data; B = number of sites sampled for disease data.

	Geographic Region	A	B
1.	Upper Bay mainstem	3	1
2.	Chester River Region	2	2
3.	Middle Rivers - Upper Bay	1	0
4.	Lower Rivers - Upper Bay	1	1
5.	Eastern Bay	4	3
6.	Miles-Wye Rivers	4	3
7.	Mid-Bay mainstem	4	3
8.	Lower Choptank River	7	6
9.	Upper Choptank River	2	2
10.	Little Choptank River	2	2
11.	Lower Bay mainstem	1	1
12.	Honga River	2	1
13.	Fishing Bay	2	1
14.	Nanticoke-Wicomico Rivers	5	1
15.	Manokin-Big Annemessex Rivers	2	1
16.	Pokomoke Sound	2	1
17.	Tangier Sound	7	5
18.	Lower Potomac River	3	3
19.	Mid-Potomac River	5	2
20.	Wicomico (Potomac) River	2	2
21.	Patuxent River	3	2

In 1990, the mode of spatfall was in the 1-19 spat per bushel frequency class (approximately 45% of the survey sites), whereas only 6% of the sites had over 200 spat per bushel. Spatfall in 1991 was bimodal, with peaks in the 20-99 (22%) and ≥300 spat per bushel (23%) ran

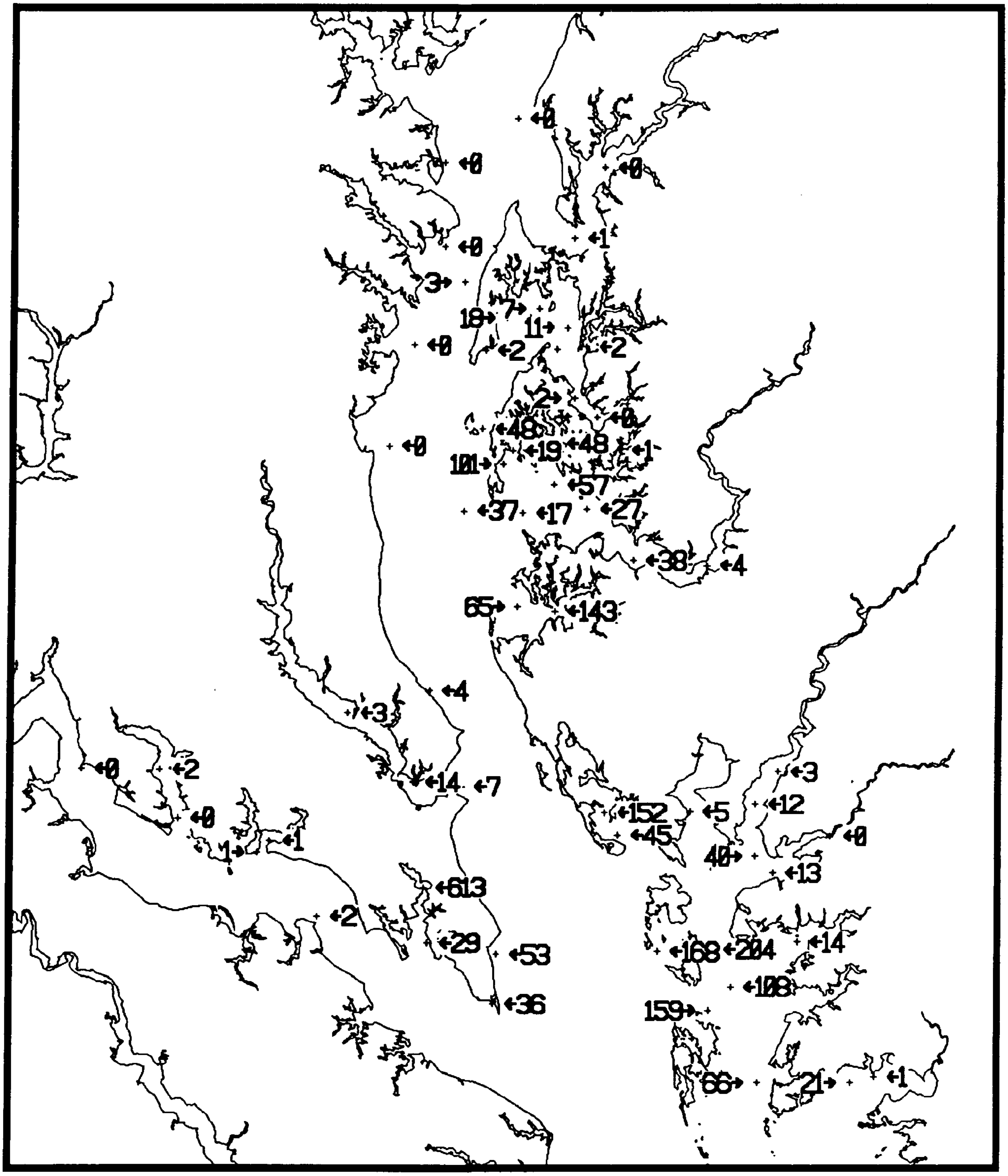

Figure 4. Spat density per bushel of substrate by site, 1990.

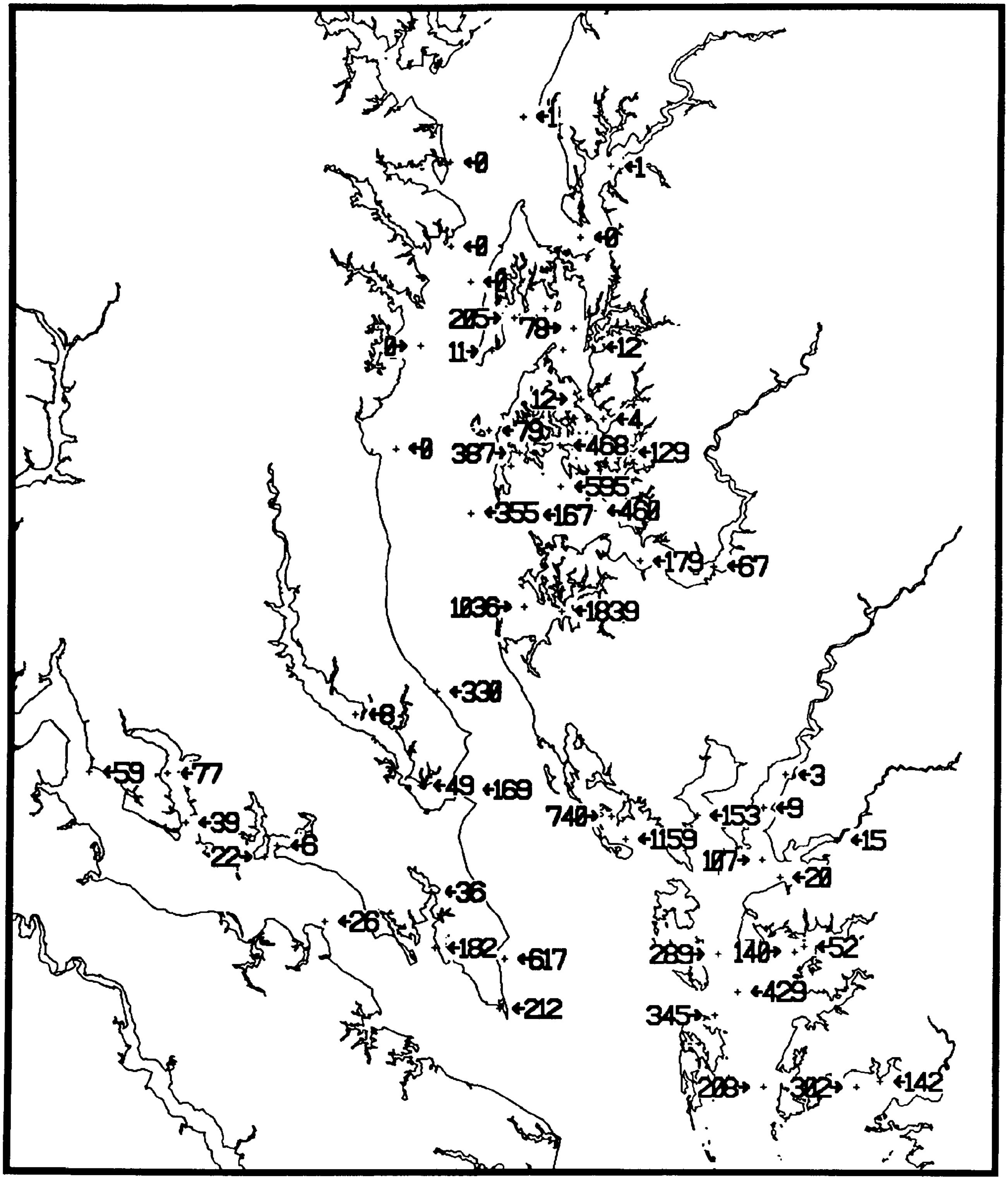

Figure 5. Spat density per bushel of substrate by site, 1991.

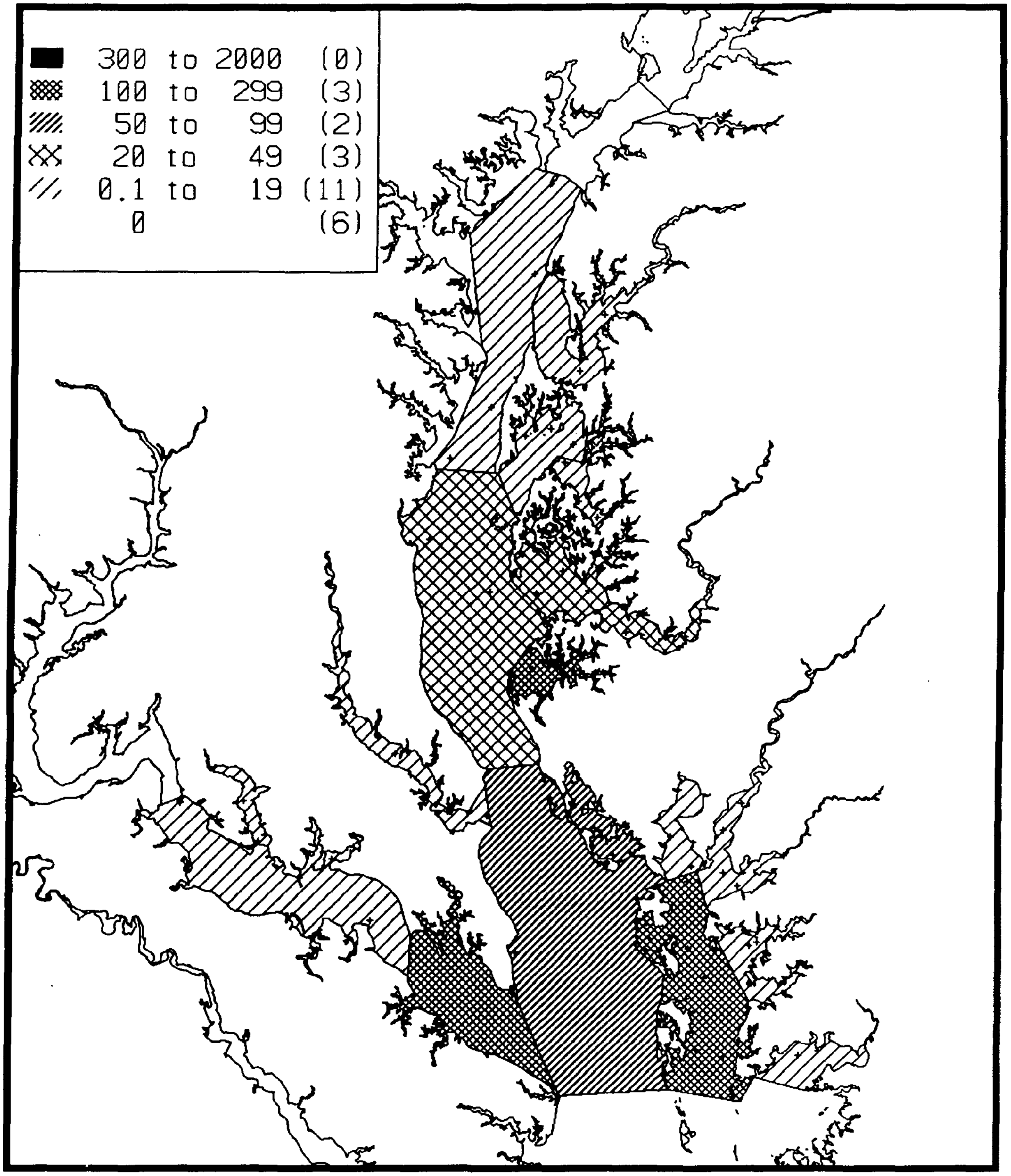

Figure 6. Average spat density ranges for geographic regions, 1990. Shading does not reflect oyster growing bottom. Numbers in parentheses are the numbers of sites within each region.

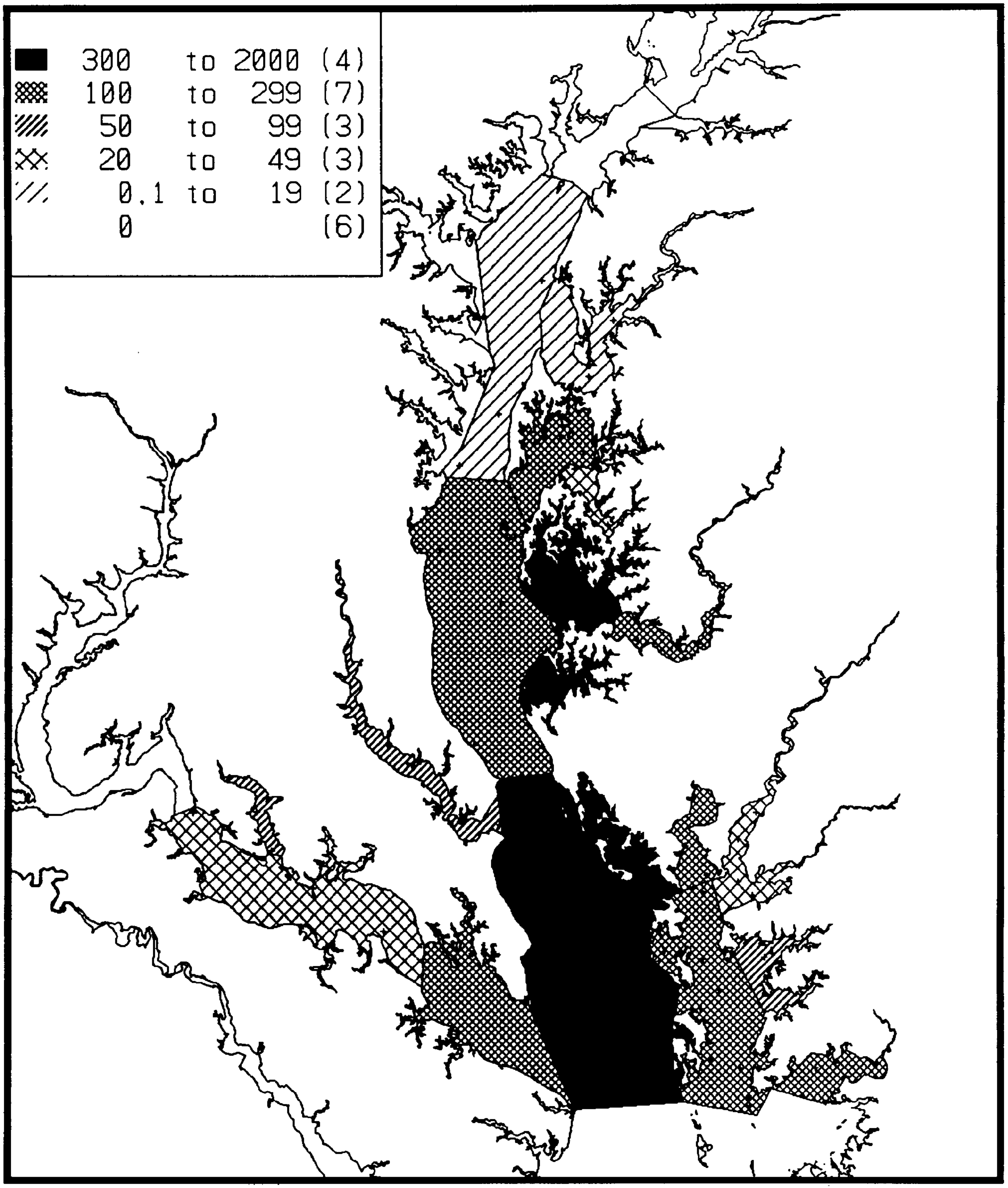

Figure 7. Average spat density ranges for geographic regions, 1991. Shading does not reflect oyster growing bottom. Numbers in parentheses are the numbers of sites within each region.

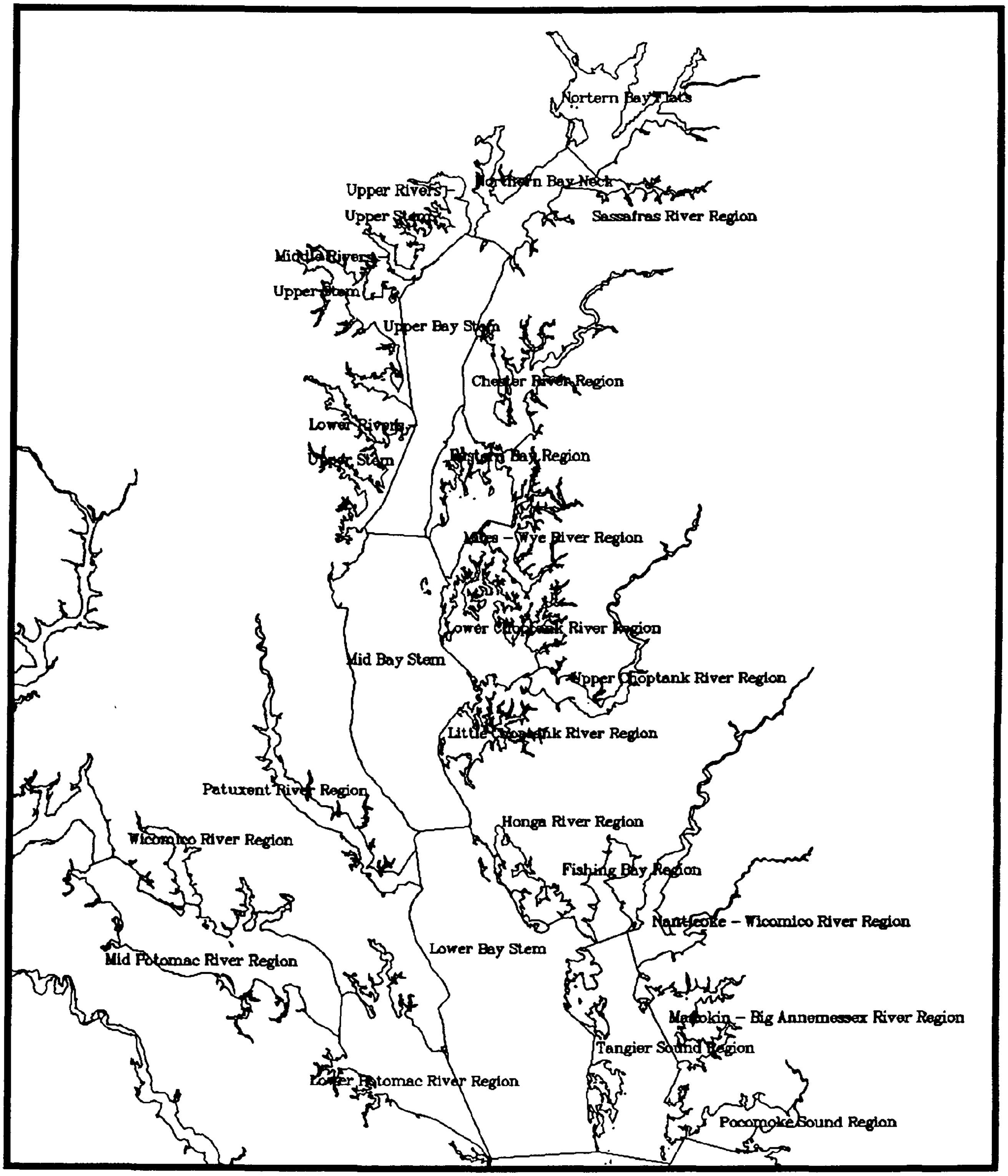

Figure 8. Geographic regions defined for aggregated analysis of oyster population data.

ges. Thirty-two percent of the sites had over 200 spat per bushel (Figure 9).

Regional variation in spatfall between years showed a similar pattern. In 1990, the great majority of the Bay's oyster regions produced spatfall levels of <20 per bushel (Figure 10). Only three regions had spat counts of >100 per bushel. This situation reversed in 1991: more than half of the regions had spat counts >100; four regions had >300 spat per bushel.

Recruitment of Spat into Fishery
A crude perspective on 1990 and 1991 spatfall in terms of potential for the future fishery can be gained by comparing spat densities to densities of the larger size classes (Figure 11). Because surviving 1990 spat should appear primarily in the 27-62mm size classes in 1991, the 1990 year class will make only a small contribution to the future fishery. The approximate five-fold increase in spat production in 1991 would be expected to have a much greater impact on population structure in 1992 and subsequent years, assuming equivalent survival.

Spatfall by Harvest Region
Spat data also can be represented within a framework of harvest regions (Figure 12; Table 3) as an alternative to the somewhat arbitrary geographic segmentation employed above. Except for the Northern Bay region and the Potomac River, all harvest regions showed substantial spatfall increases in 1991 over 1990 (Figure 13). The most marked increases were in the Choptank River-Little Choptank River (CR-LCR) and Fishing Bay-Honga River regions (FB-HR). In this representation, the inclusion of the Little Choptank River in the Choptank fishery region had a strong positive influence on the aggregated 1991 spat counts.

Table 3. Maryland Chesapeake Bay harvest regions. Aggregated by site code prefixes. Refer to Figure 8 for geographic boundaries.

Harvest Region	Sub-regions	Sites in Subregion	Sites in Region
BN	BN - Bay North	2	7
	UB - Upper Bay	3	
	CH - Chester River	2	
EB	EB - Eastern Bay	4	8
	MR - Miles River	4	
CR	CR - Choptank River	6	11
	BC - Broad Creek	1	
	HC - Harris Creek	1	
	TA - Tred Avon River	1	
	LC - L. Choptank R.	2	
FB	FB - Fishing Bay	2	4
	HR - Honga River	2	
WR	WR - Wicomico River	2	5
	NR - Nanticoke River	3	
TS	TS - Tangier Sound	6	11
	PS - Pocomoke Sound	2	
	MA - Manokin River	2	
	HO - Holland Straits	1	
PR	PR - Potomac River	6	10
	SM - St. Mary's River	2	
	WW - Wicomico R West	2	
PX	PX - Patuxent River	2	2
WS	WS - Western Shore	4	6
	PO - Poplar Island	1	
	ME - Mid Eastern Shore	1	

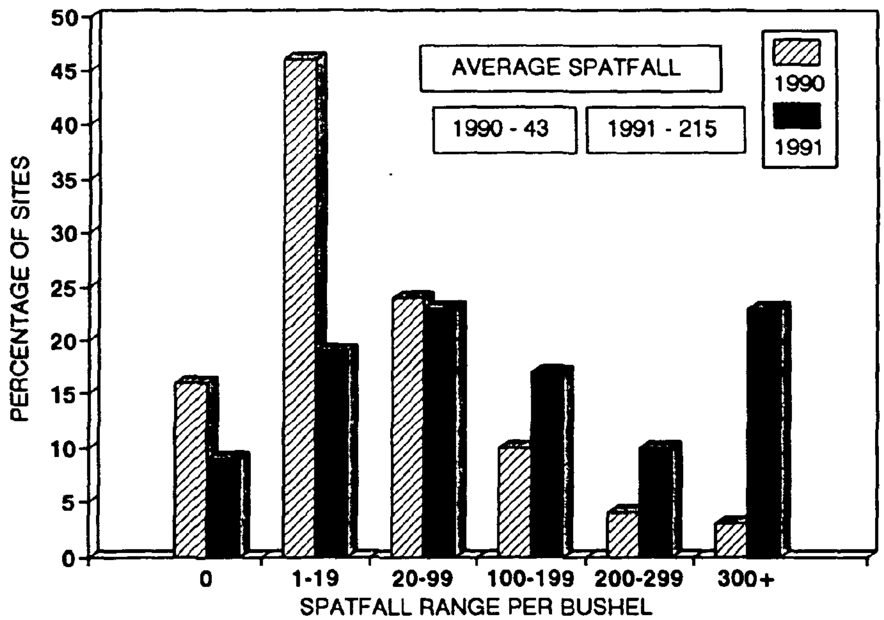

Figure 9. Comparison of spat density ranges by site for 1990 and 1991.

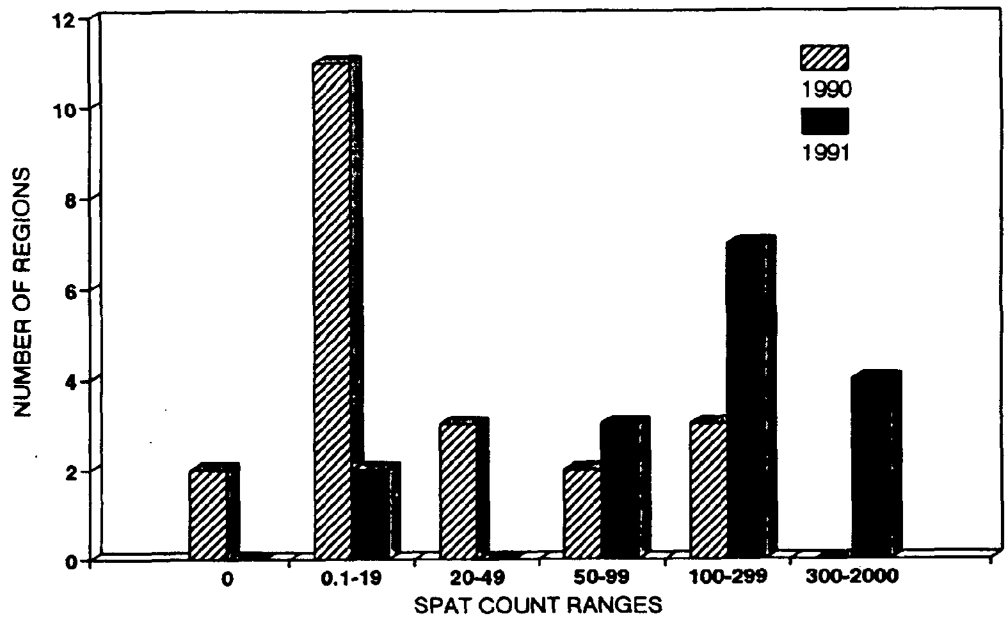

Figure 10. Comparison of spat density ranges by geographic region for 1990 and 1991.

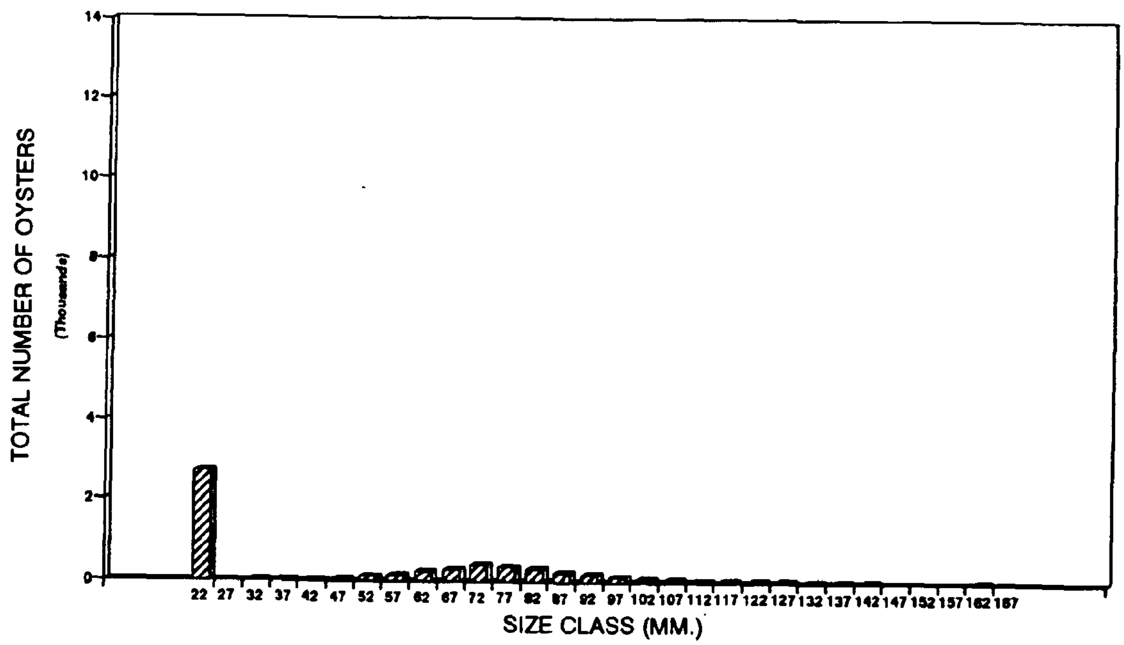

Figure 11A. Spat and older oyster densities by size class, 1990. All spat were arbitrarily assigned to the 22mm size class.

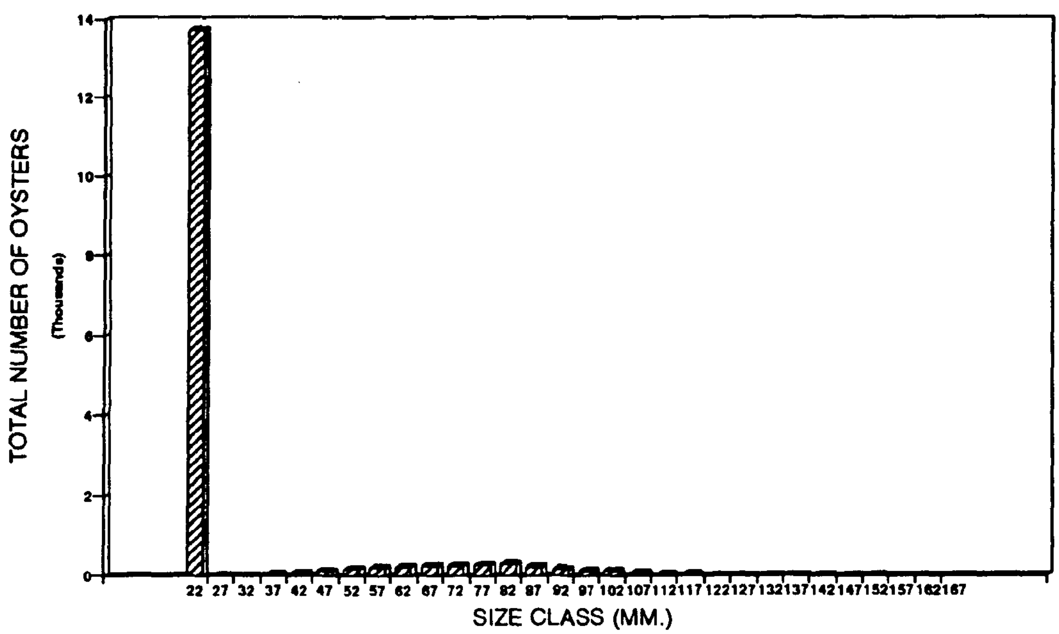

Figure 11B. Spat and older oyster densities by size class, 1991. All spat were arbitrarily assigned to the 22mm size class.

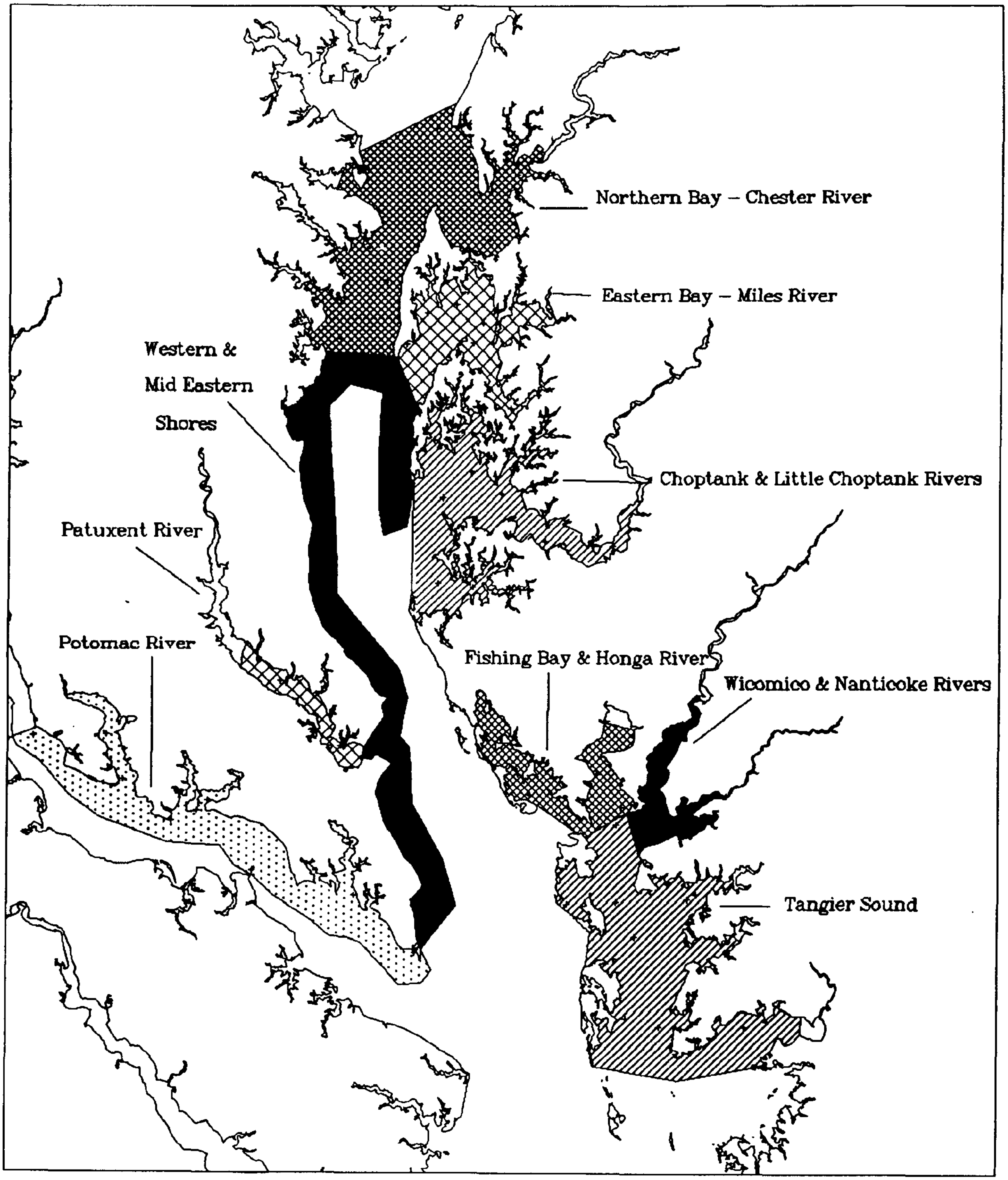

Figure 12. Oyster harvest regions

Table 4. Ratio of small oysters (presumed 1990 year class observed in fall 1991) to 1990 fall spat counts at three selected oyster bars. TSBC = Tangier Sound Back Cove; CRTW = Choptank River Tilghman Wharf; HOHO = Holland Straits, Holland Straits Bar.

TOTAL COUNTS (1.0 BUSHEL)

Site	Small	Spat	Ratio
TSBC	127	159	0.80
CRTW	139	101	1.38
HOHO	115	168	0.68

COUNTS PER 0.2 BUSHEL SUBSAMPLE

TSBC		CRTW		HOHO	
Spat	Sm.	Spat	Sm.	Spat	Sm.
29	27	19	16	11	30
36	21	28	26	28	30
34	21	35	28	27	10
31	35	51	37	15	23
29	23	35	32	20	22

Replicate Spat Sampling

The MFS design included replicate sampling for spat counts as well as for live and dead (box) oyster counts. Five replicate dredge samples were taken; a subsample of 0.2 bushel of material was removed from each (1.0 bushel total). Prior to 1990, the Fall Survey method used was one 0.5 bushel subsample, which was multiplied by 2 and reported as counts per 1.0 bushel on field sheets. Because heavy spatfall in 1991 greatly increased onboard processing time, we evaluated the usefulness of counting five subsamples as opposed to three or four.

Three ranges of spatfall were subjected to analysis: 1-19, 20-99, and ≥100 spat per bushel. The five subsamples were summed to obtain units of spat per bushel (for historical consistency). One sampling site that fell within each of the spatfall ranges was chosen at random for analysis: Miles River-Ashcraft (MRAS; 1-19 spat per bushel); Poplar Island-Shell Hill (POSH; 20-99), and Western Shore-Hog Island (WSHI; ≥100). Subsample values were converted to a 1.0 bushel basis (x5) prior to analysis.

Confidence limits (95%) based upon the standard error of the mean were calculated for each site for various numbers of replicate samples. Subsamples were removed at random to obtain confidence intervals for reduced numbers of replicates.

At WSHI, use of five replicates produced confidence limits of 108-229 spat per bushel (Figure 14). Thus, if any number of five replicate samples were taken at that site, 95% of the time the average of these spat counts would fall within these confidence limits. With four subsamples, the 95% confidence limits increased to 78-241. With three subsamples, the 95% confidence limits were 9-287.

For the mid-range site (POSH), a similar increase in the confidence limits occurred as subsamples were deleted: from 52-79 spat per bushel with five subsamples, to <0-85 with three subsamples. At the low spatfall site (MRAS), there was an apparent increase in precision with decreasing sample size. Two factors were responsible for this anomaly: 1) random deletion of subsamples by chance removed the highest spat counts; 2) some remaining samples had spat counts of zero. These effects reduced both the range and mean and suggested that spat counts within this low range cannot be distinguished statistically from zero (for a single site), based upon the current sampling protocols. The results nevertheless showed that a meaningful increase in precision was provided by additional

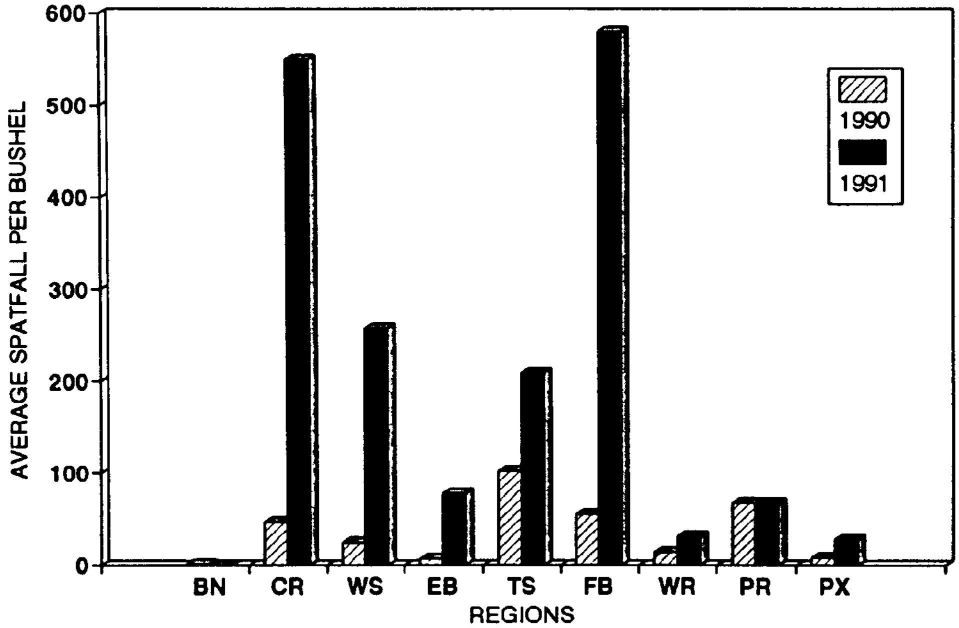

Figure 13. Spat densities averaged by harvest regions, 1990 and 1991.

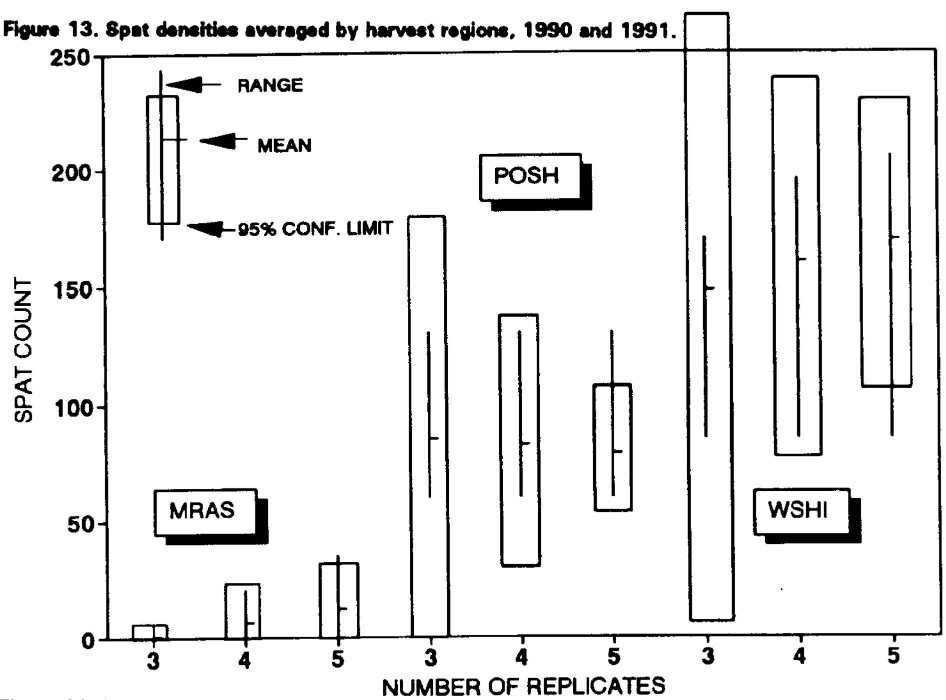

Figure 14. Influence of number of replicate spat counts on 95% confidence limits for mean spat counts at three sites, 1991. MRAS = Miles River-Ashcraft; POSH = Poplar Island-Shell Hill; WSHI = Western Shore-Hog Island.

subsamples at the two sites averaging greater than 20 spat per bushel.

Recruitment of Spat into Year Class Population Structure

Three sites were chosen for analysis to determine the correlation between 1990 spatfall and recruitment into the 1+ year class (presumptive 1990 spat measured in 1991). Site selection was based on the requirement of 1990 spatfall numbers sufficient to observe their incorporation into 1991 size class structure. Because 1990 spatfall was light, as well as limited in regional distribution, the choice of sites was quite limited. Within these limitations, the three sites were chosen for geographic diversity.

Ratios of 1990 spat to 1991 small (<3 in., 1+ year class) oysters for TSBC (Tangier Sound-Back Cove) and HOHO (Holland Straits-Holland Straits) were reasonable, with 80% and 68% apparent survival of spat into the second year (Table 4). Results for CRTW (Choptank River-Tilghman Wharf) were anomalous, with 38% more year 1+ oysters present in the 1991 sample than the 1990 spat sample count. Sites TSBC and HOHO, while showing marked decreases in oyster numbers between spat and year 1+ oysters, also exhibited overlap of confidence limits (Figure 15). Thus, although ratios indicated decreases in abundance, there was no clear statistical discrimination between the two samples (at 95% confidence). Likewise, the apparently counterintuitive trend at CRTW was not persuasive given the large overlap of confidence intervals.

Population Structure and Mortality

Mortality Statistics

Mortality between 1990 and 1991 increased at virtually every sampling site in the Maryland Bay (Figures 16 and 17). Overall, small and market oyster mortality increased from 17% in 1990 to 31% in 1991 (Table 5). Mortality statistics on a site by site basis are presented in Appendix C. In 1990, the majority of Bay regions showed mortalities of less than 30% with much of the upper Bay having low mortalities (Figure 18). This situation changed greatly in 1991, with both increases in mortality within most Bay regions as well higher mortalities in the upper Bay region (Figure 19).

Table 5. Comparisons of mortality indices averaged (summed) over 63 (1990) or 64 (1991) MFS sites. Numbers without units are counts. Recent mortality = gapers + stage 1 boxes + stage 2 boxes; markets are ≥3 in. (76mm) in shell height; smalls are <3 in.

	1990	1991
Live oysters	96 (6052)	87 (5541)
Boxes	20 (1250)	39 (2523)
Small/market ratio	2.9	2.9
Market boxes	9 (538)	20 (1279)
Small boxes	11 (712)	19 (1244)
Recent market boxes	2 (139)	2 (132)
Recent small boxes	4 (278)	4 (261)
Total mortality (%)	17	31
Market mortality (%)	20	38
Small mortality (%)	16	26
Recent mortality (%)	6	7
Recent market mortality (%)	6	8
Recent small mortality (%)	6	6
Mean length, recent boxes (mm)	54	63
Mean length, all boxes (mm)	79	79

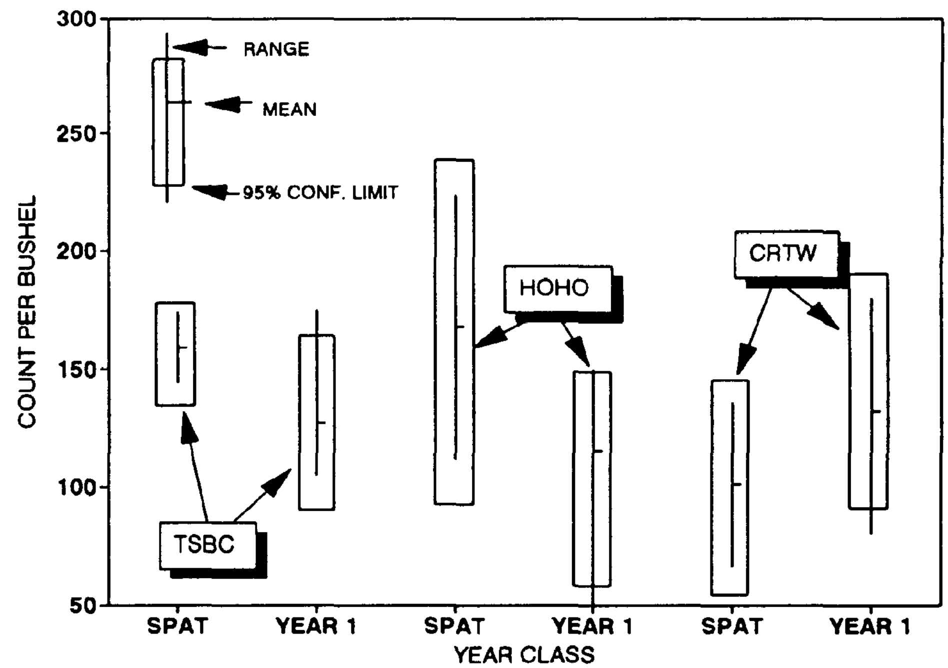

Figure 15. Comparison of 1990 spat counts to counts of 1991 presumptive yearling oysters at three sites. TSCB = Tangier Sound-Back Cove; HOHO = Holland Straits-Holland Straits; CRTW = Choptank River Tilghman Wharf.

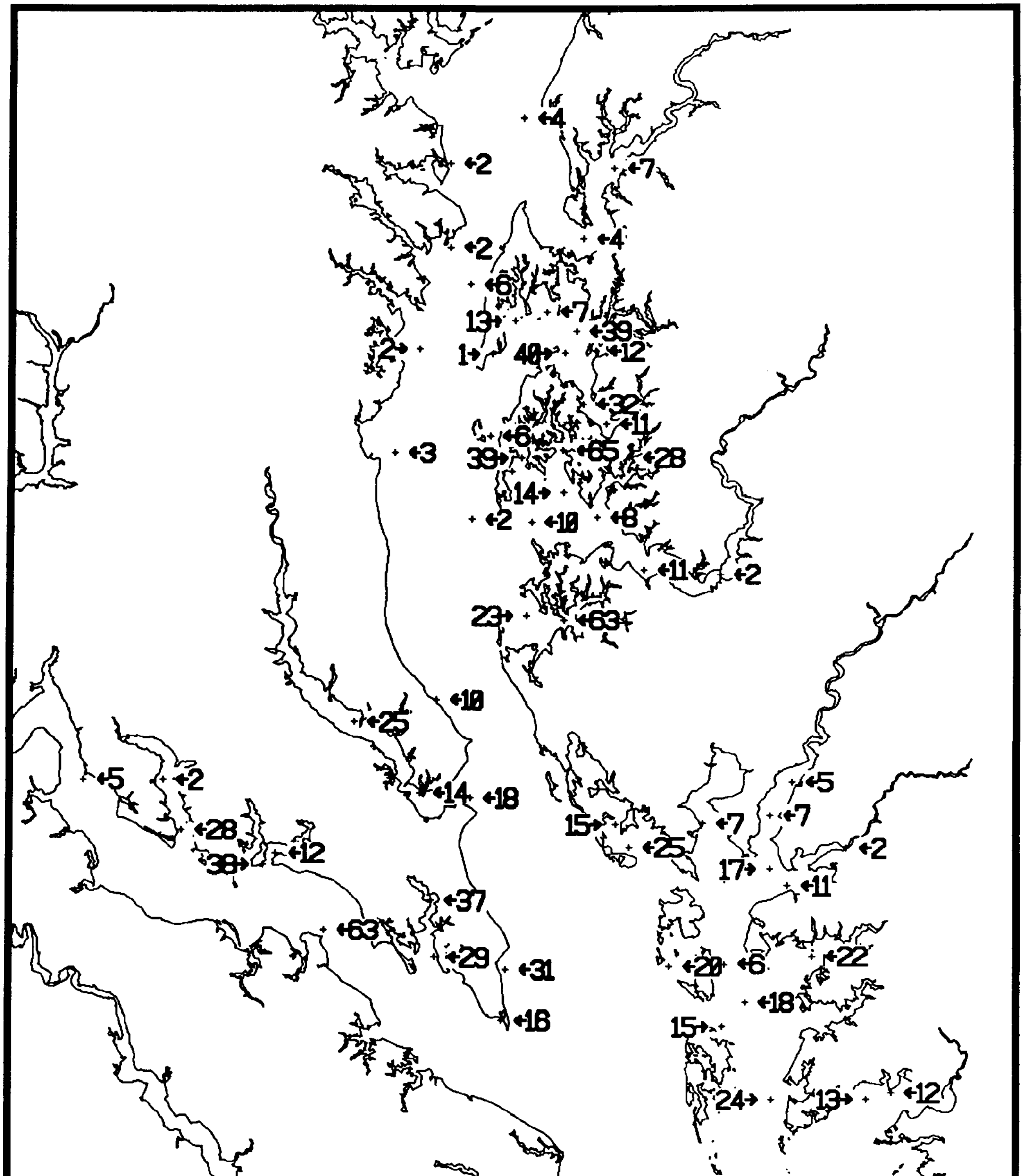

Figure 16. Oyster mortality (percent boxes) by sampling site, 1990.

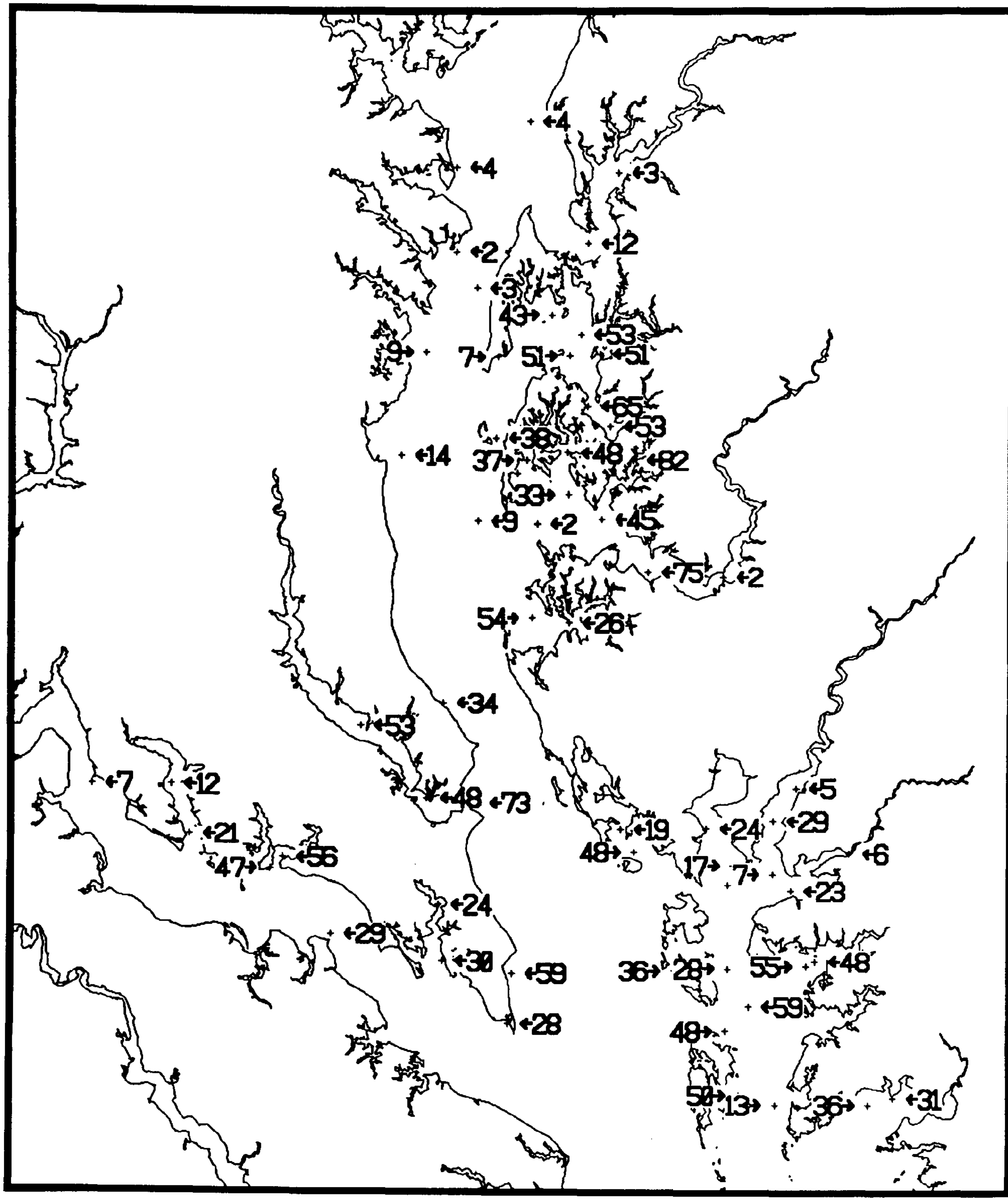

Figure 17. Oyster mortality (percent boxes) by sampling site, 1991.

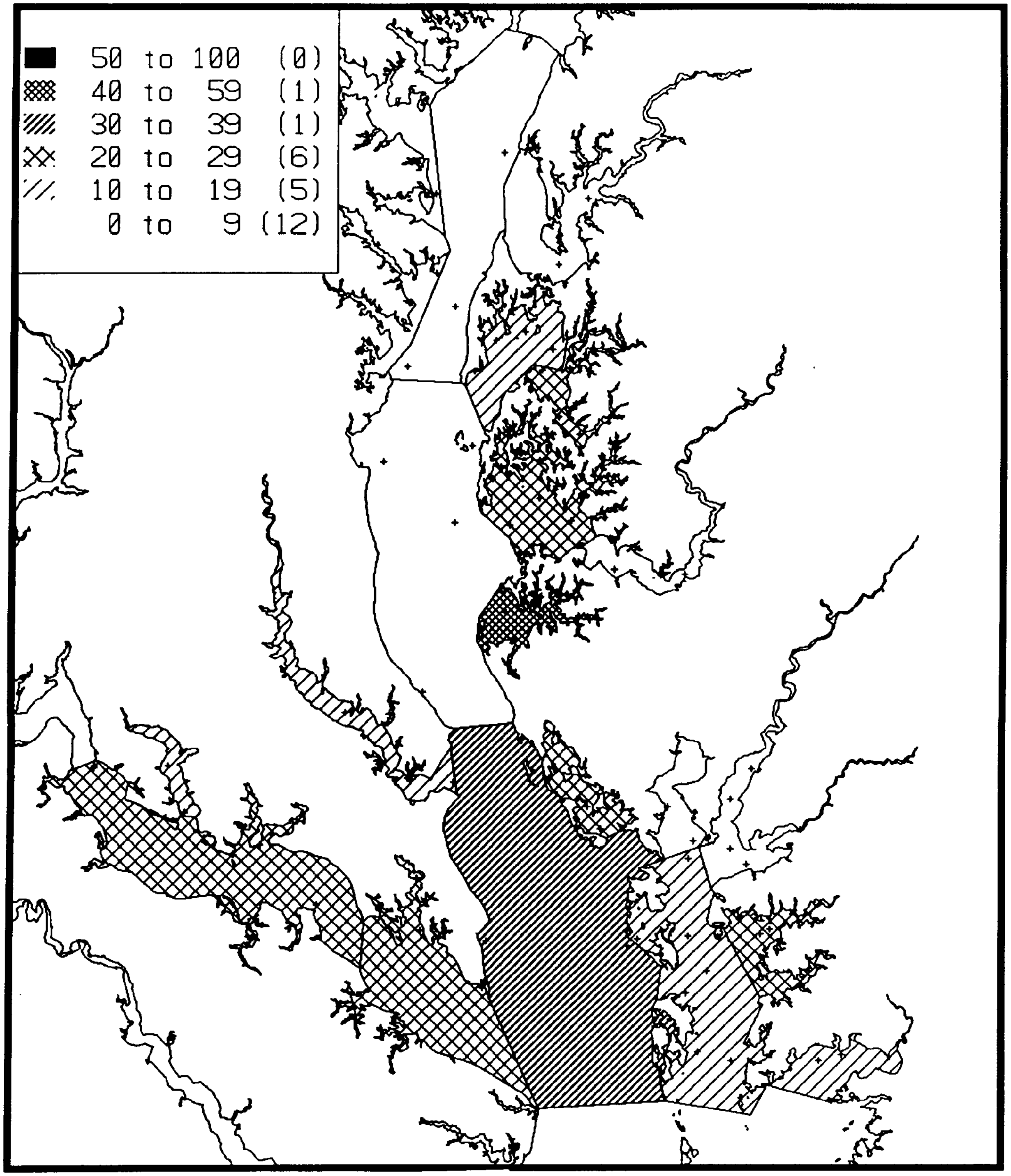

Figure 18. Oyster mortality averaged by geographic regions, 1990.

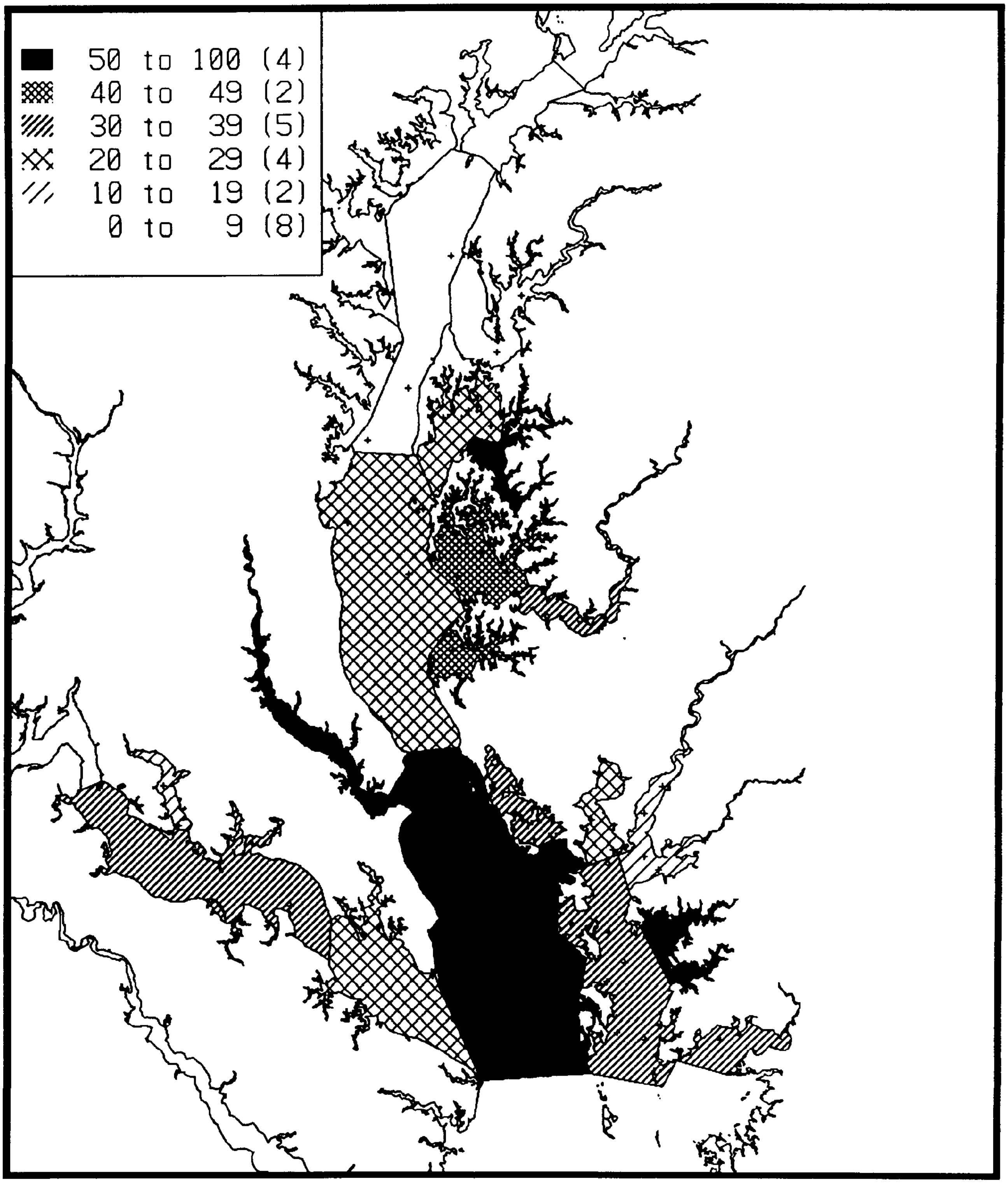

Figure 19. Oyster mortality averaged by geographic regions, 1991.

In 1990, the mode of mortality aggregated on a regional basis was in the 0-9% range. In 1991, the modal range of mortality was 30-39%. From 1990 to 1991, the number of regions with <30% mortality decreased, whereas the number with >30% mortality increased (Figure 20). There was a marked increase in the ≥50% mortality class; in 1990, no Bay regions averaged >50% mortality, whereas in 1991 four regions fell within this category.

Mean mortality estimates for six of the nine harvest regions were considerably greater in 1991 than in 1990 (Figure 21). Three regions—Northern Bay-Chester River (NB-CR), Wicomico-Nanticoke Rivers (WR-NR), and Potomac River (PR)—had only slight increases in mortality.

On a Baywide basis, the average number of live market oysters (≥3 in.) per bushel decreased between 1990 and 1991, while the number of market boxes increased (Figure 22). The majority of the increased natural mortality apparently occurred at least a month before the survey (October-November), as the numbers of recently dead oysters remained nearly constant between 1990 and 1991 (Figure 23).

Baywide Population Size Structure

Virtually all oysters sampled during both years of the survey fell between 30mm (1.2 in.) and 150mm (5.9 in.; Figures 24 and 25). Peak oyster size abundance (including boxes) was slightly less than 75mm (2.9 in.) in both years. In 1990, the distribution of live oyster lengths was symmetrical about this center of abundance. In 1991, two peaks of live oyster abundance were observed: 1) the peak centered at just over 80mm could reflect the much reduced 1990 population which was centered at 75mm at the time of the 1990 survey, and 2) the peak centered at approximately 50mm incorporated 1990 spat as well as an undetermined number of seed oysters transplanted to survey oyster bars.

Overall natural mortality in 1990 was much lower than in 1991. The most abundant size of boxes was 60-90mm. The two-peaked size distribution in 1991 was also apparent with combined live oysters and boxes. Peak box counts were in the 50-100mm range.

There was substantial depletion of live oysters relative to the total sample within the span of a year (Figure 26). No overall growth of the population in terms of size increases between the time of the 1990 MFS survey and that of the 1991 MFS survey was observed.

Regional Population Age Structures

There was substantial variation in population structure and relative oyster abundance between harvest regions (Figures 27-35). Note that the vertical axes of these figures differ. Some distinctive characteristics within regions were observable and are discussed below. Although year classes are identified as discrete entities, it should be realized that due to variations in individual growth rates, oysters of different year classes may in fact be mixed together. Due to this effect, year classes of 3+ or greater are difficult to quantify accurately.

Northern Bay and Chester River

Size frequency patterns were very different between the two years (Figure 27). In 1990, what appears by modal size to be a 2+ year class dominated the population structure. What

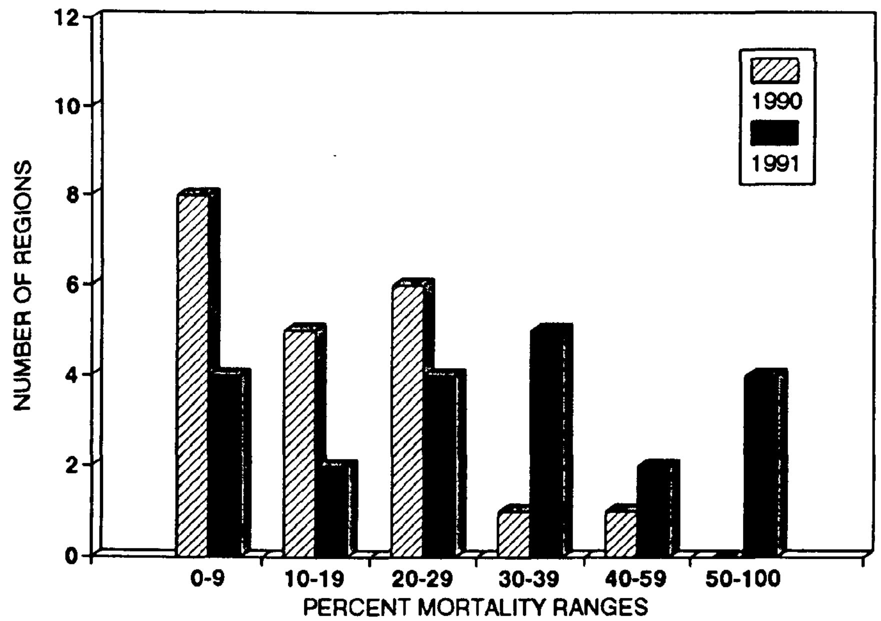

Figure 20. Ranges of mortality by geographic regions.

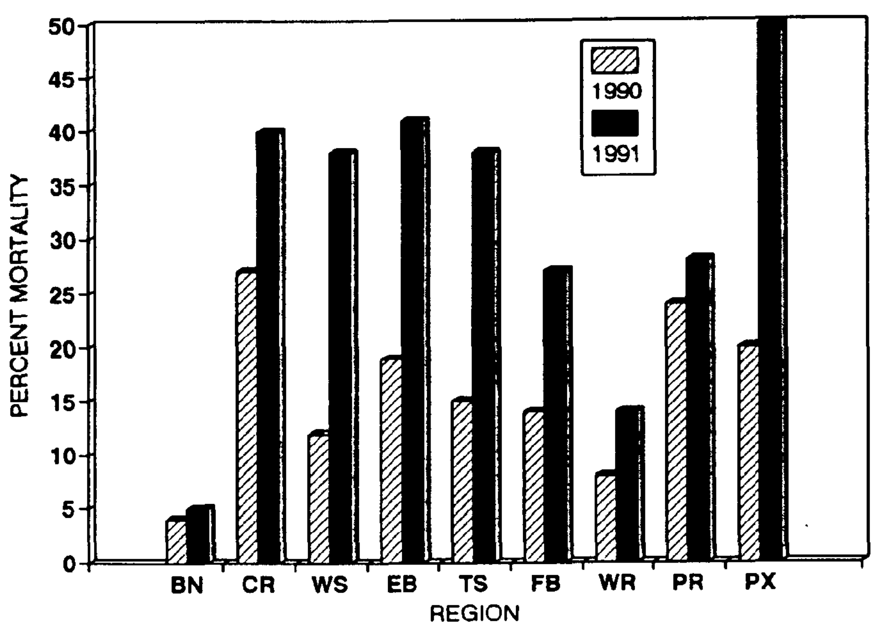

Figure 21. Ranges of mortality by harvest regions.

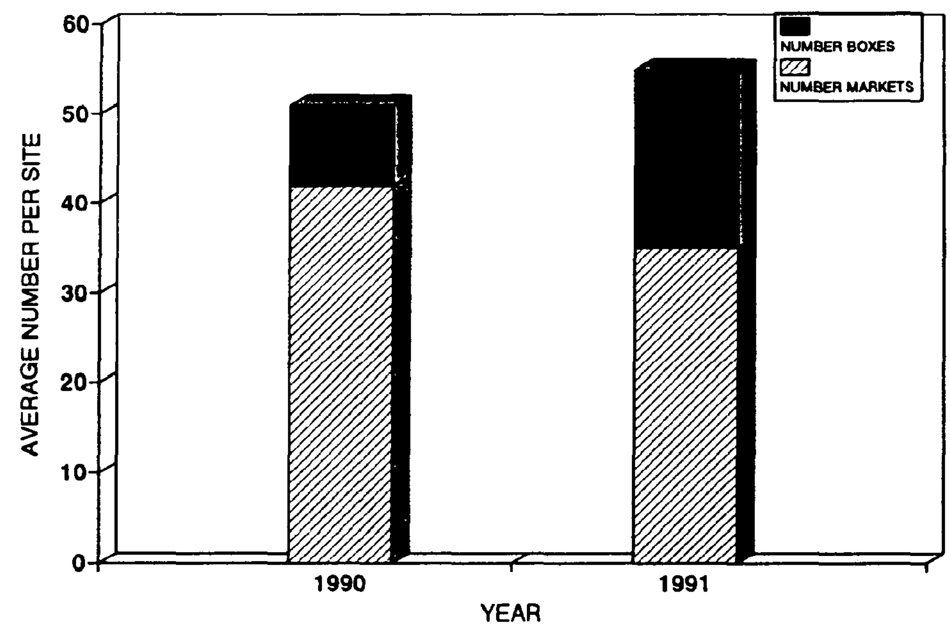

Figure 22. Baywide averages of market-sized (≥76mm) live oysters and boxes.

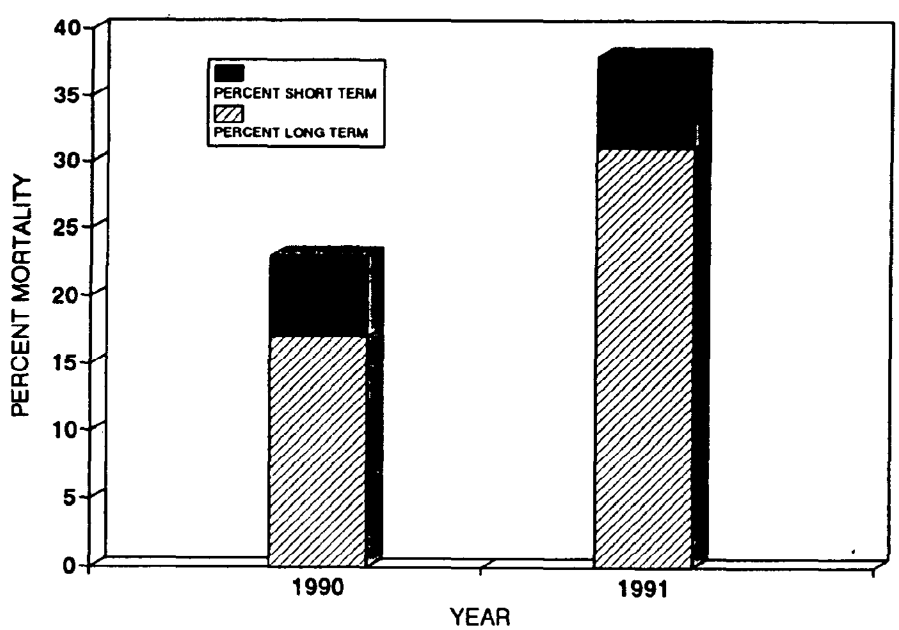

Figure 23. Baywide averages of long-term (percent of boxes estimated to be more than a few weeks past death), short-term, and total mortality.

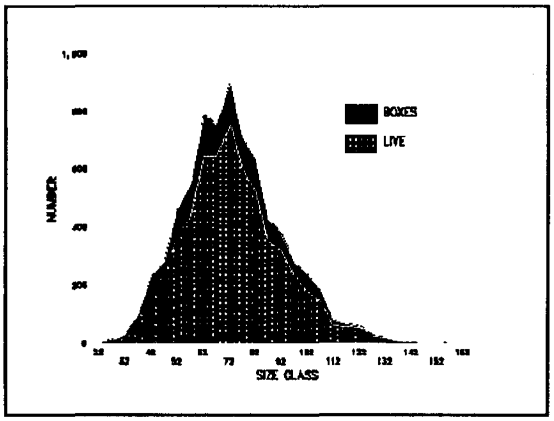

Figure 24: Cumulative numbers of live and box oysters collected from all sites in Maryland Chesapeake Bay, 1990.

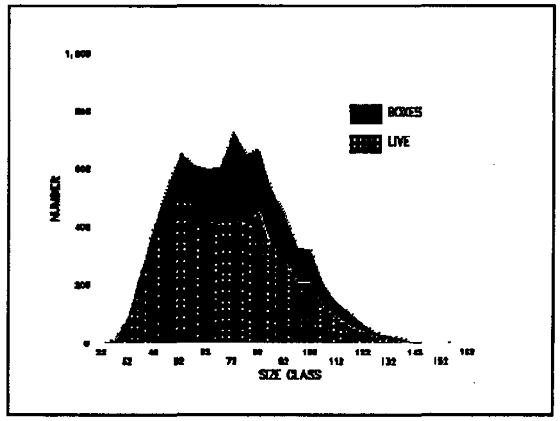

Figure 25. Cumulative number of live and box oysters, collected from all sites in Maryland Chesapeake Bay, 1991.

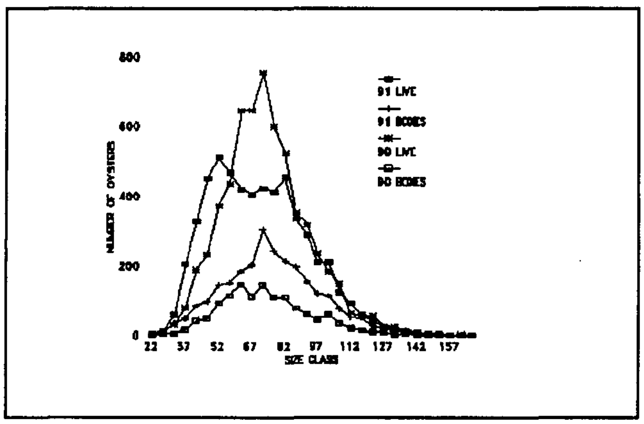

Figure 26. Total numbers of live and box oysters collected from all sites in Maryland Chesapeake Bay, 1990 and 1991.

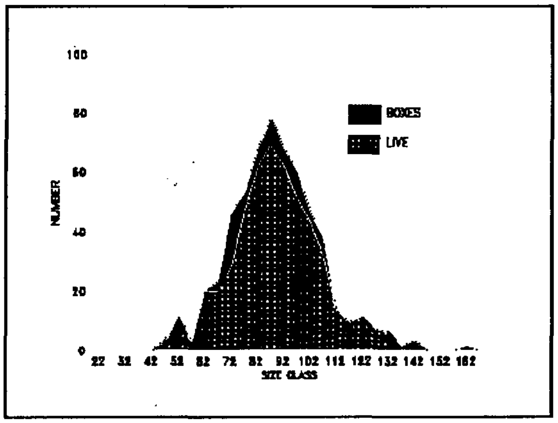

Figure 27a. Total number of survey oysters by component, Northern Bay - Chester River harvest region, 1990.

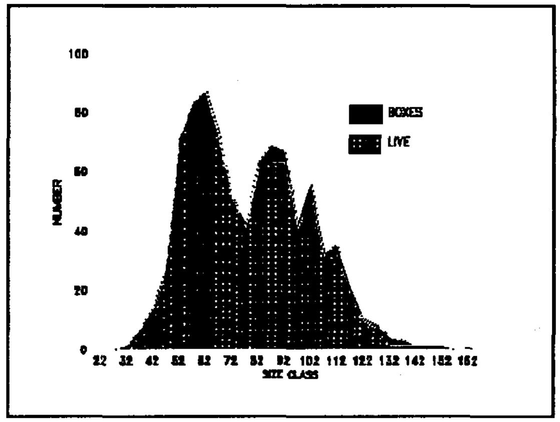

Figure 27b. Total number of survey oysters by component, Northern Bay - Chester River harvest region, 1991.

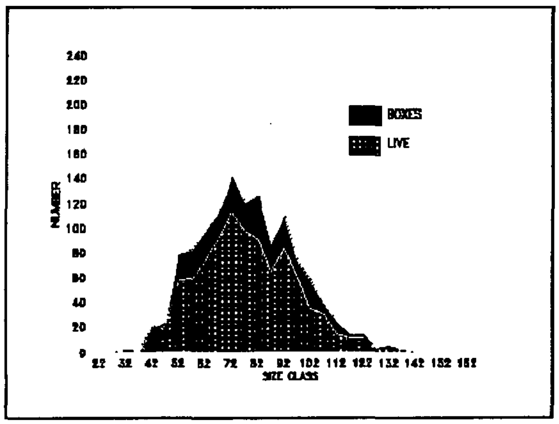

Figure 28a. Total number of survey oysters by component, Choptank River - Little Choptank River harvest region, 1990.

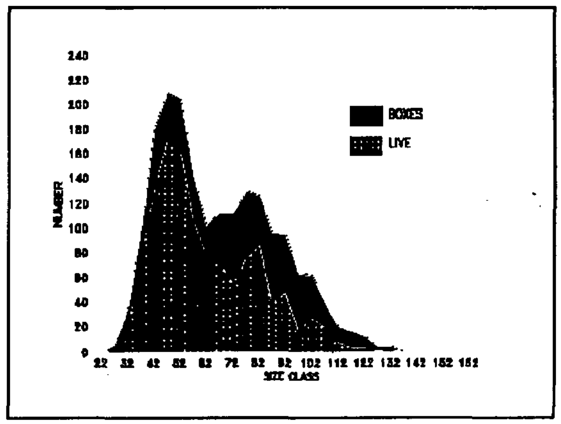

Figure 28b. Total number of survey oysters by component, Choptank River - Little Choptank River harvest region, 1991.

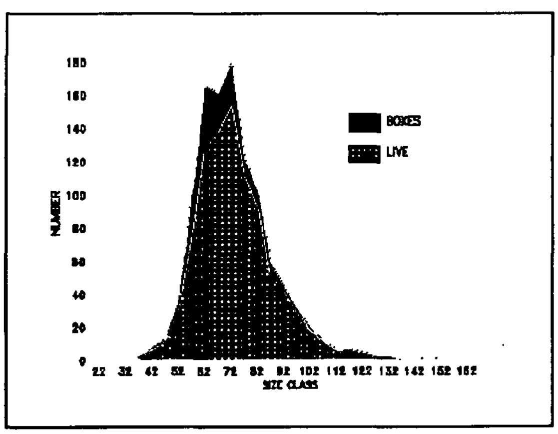

Figure 29a. Total number of survey oysters by component, Western Shore - Mid Eastern Shore harvest region, 1990.

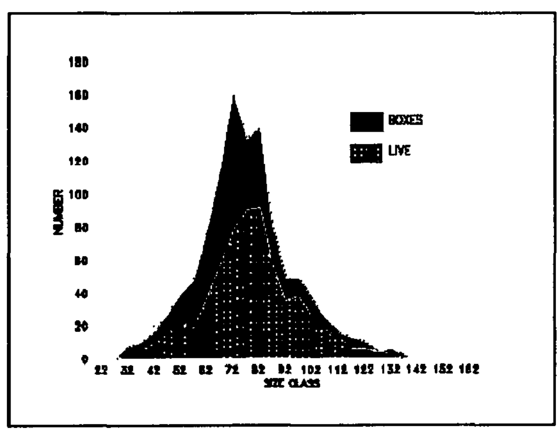

Figure 29b. Total number of survey oysters by component, Western Shore - Mid Eastern Shore harvest region, 1991.

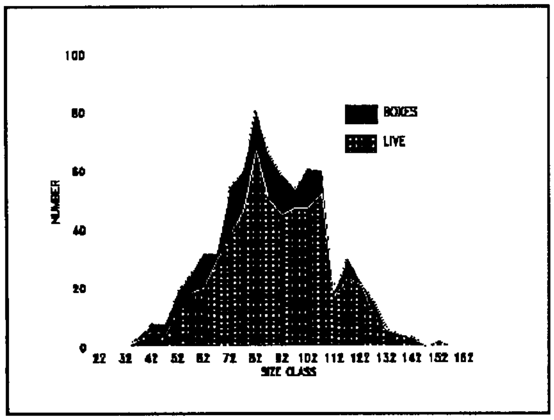

Figure 30a. Total number of survey oysters by component, Eastern Bay - Miles River harvest region, 1990.

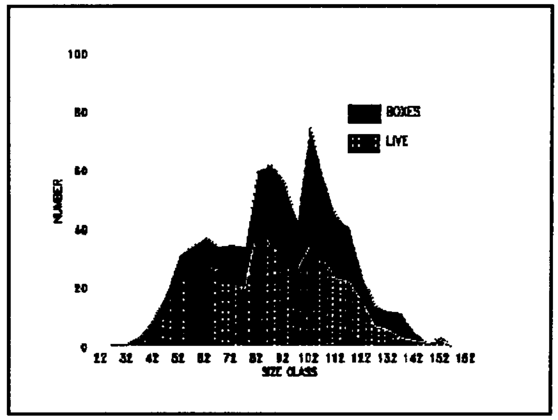

Figure 30b. Total number of survey oysters by component, Eastern Bay - Miles River harvest region, 1991.

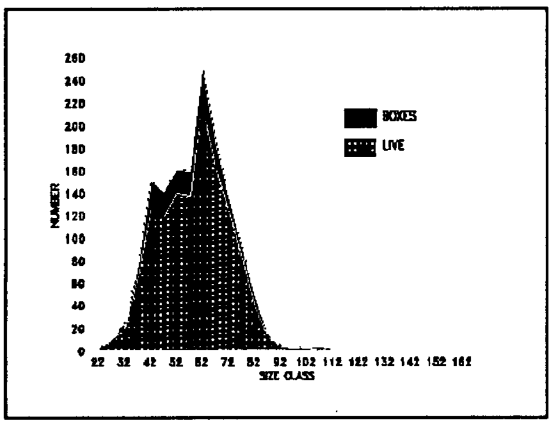

Figure 31a. Total number of survey oysters by component, Tangier Sound harvest region, 1990.

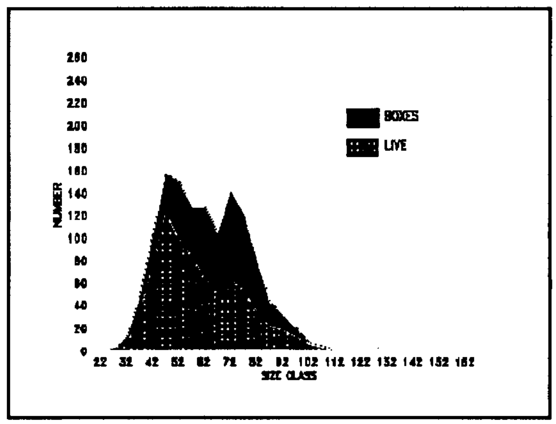

Figure 31b. Total number of survey oysters by component, Tangier Sound harvest region, 1991.

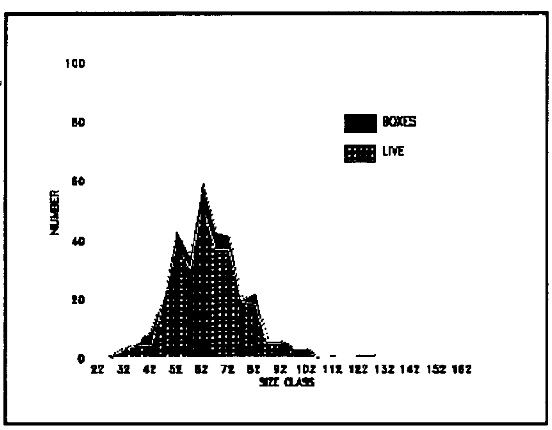

Figure 32a. Total number of survey oysters by component, Fishing Bay - Honga River harvest region, 1990.

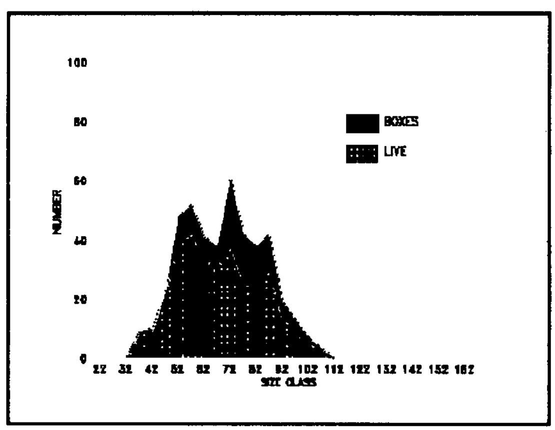

Figure 32b. Total number of survey oysters by component, Fishing Bay - Honga River harvest region, 1991.

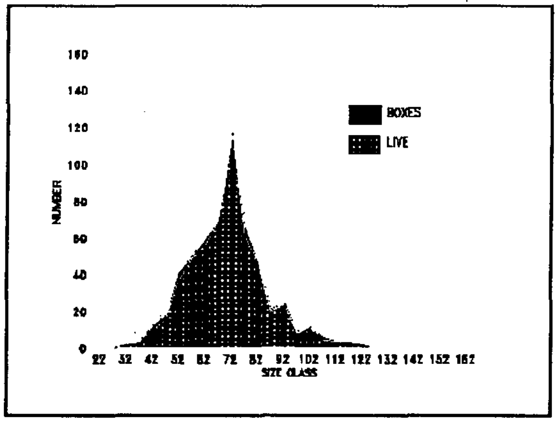

Figure 33a. Total number of survey oysters by component, Wicomico River - Nanticoke River harvest region, 1990.

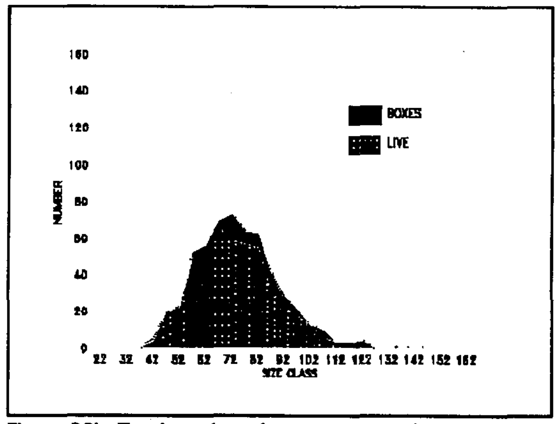

Figure 33b. Total number of survey oysters by component, Wicomico River - Nanticoke River harvest region, 1991.

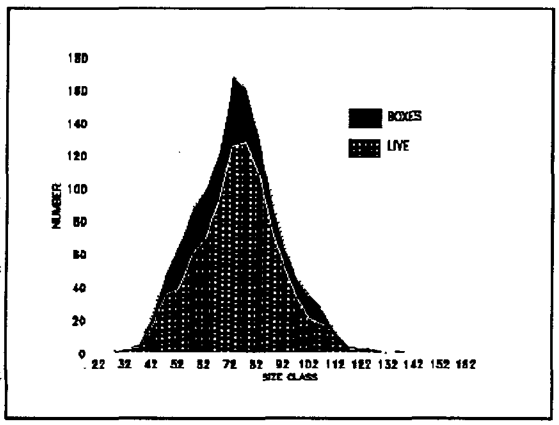

Figure 34a. Total number of survey oysters by component, Potomac River harvest region, 1990.

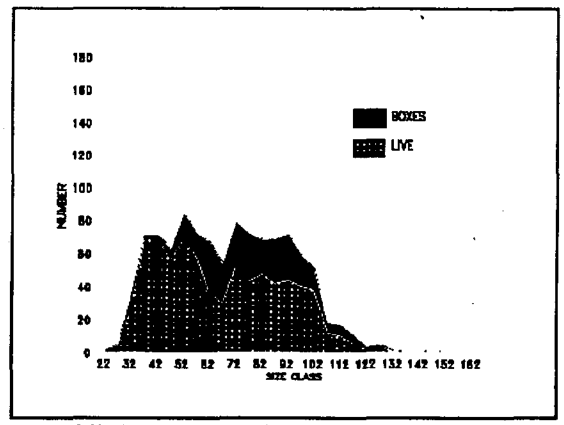

Figure 34b. Total number of survey oysters by component, Potomac River harvest region, 1991.

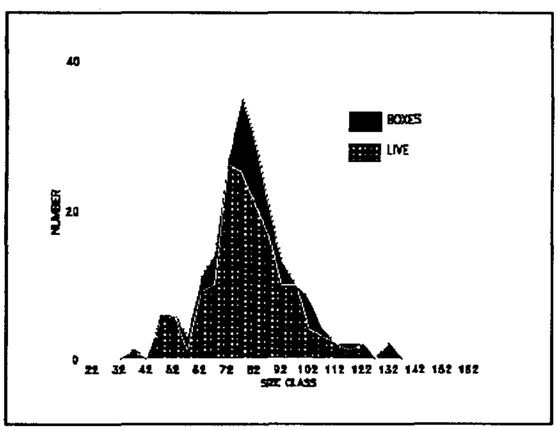

Figure 35a. Total number of survey oysters by component, Patuxent River harvest region, 1990.

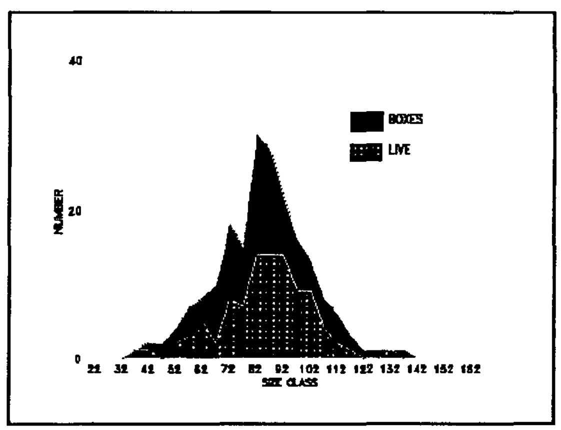

Figure 35b. Total number of survey oysters by component, Patuxent River harvest region, 1991.

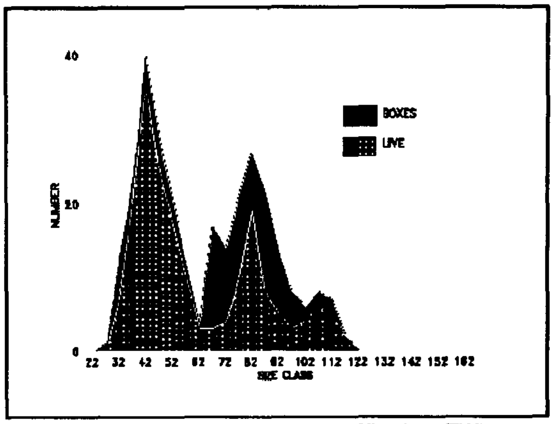

Figure 36. Choptank River - Tilghman Wharf (CRTW) oyster bar, 1991.

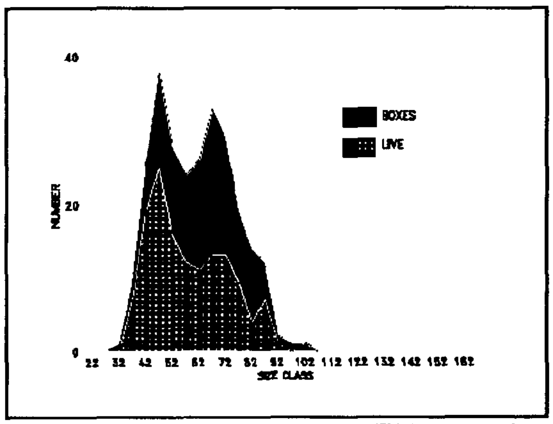

Figure 37. Tangier Sound - Back Cove (TSBC) oyster bar, 1991.

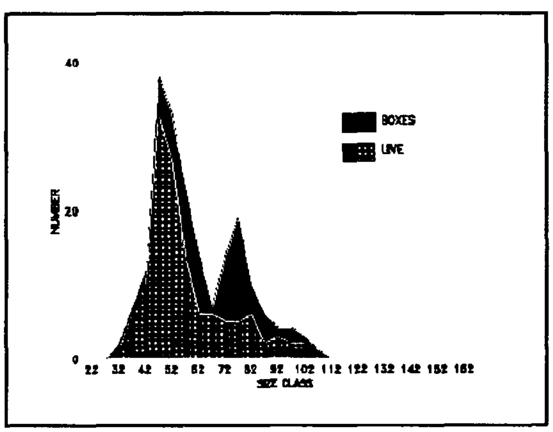

Figure 38. Holland Straights - Holland Straights (HOHO) oyster bar, 1991.

component of this is older seed plant cannot be determined. An almost total absence of the 1+ year class (1990 spat or seed) was apparent. In 1991, the presumed 1+ year class was a significant addition to the population. Because spatfall was negligible in this region in 1990, the large 1+ year class may have represented extensive seed plantings in the Chester River. The 2+ size group of 1990 grew slightly to form the 3+ year class centered at approximately 100mm. There was a slight increase in mortality in this size class in 1991. It was tempting to interpret the several clear peaks of the 1991 distribution as discrete age classes, but not clear how these groups could have derived from the 1990 distribution.

Choptank and Little Choptank Rivers

The 1990 presumed 2+ year class (75 mm) and a possible 3+ year class (95 mm) showed moderate mortality (Figure 28). In 1991, these two groups had >50% mortality. The 1+ year class in 1991 (1990 set) was large in comparison to the population, but was showing the beginnings of high mortality.

Western Shore and Mid-Eastern Shore

The 1990 population showed what appeared to be largely one year class centered at 75mm (Figure 29). Mortality was light to moderate and expressed itself largely in the 60-75 mm range. If year classes other than the apparent 2+ year class were present, they were incorporated within the structure of this age group.

In 1991, mortality was high for this age group (possibly >50%). Slight growth (~10mm) was shown by the live component of this age class. Presence of a small 1+ year class was also visible. This new year class was also showing high mortality levels.

Eastern Bay and Miles River

In 1990, the 2+ year class (~80mm) and 3+ year class (~100-105mm) were beginning to show high levels of mortality (Figure 30). In 1991, these two year classes had grown very little and had experienced >50% mortality. Incorporation of a modest 1+ year class and or seed plantings occurred in 1991. High mortalities were apparent in this young age group.

Tangier Sound

A possible intrepretation of Tangier Sound data in 1990 would be a small 1+ year class with a mode at approximately 40mm, and a larger 2+ year class with a mode at approximately 60mm. Light to moderate mortality was present in these year classes (Figure 31). In 1991, the fate of these year classes was not entirely clear. Spatfall in the Tangier Sound region in 1990 averaged 100 per bushel. This age group (1+) might have been centered at 50mm in 1991. The peak at 75mm, then, might have been the 2+ year class, i.e., the 1+ year class in 1990. In any case, it appeared that one year class, either the 2+ or 3+, disappeared as a discrete entity from the population. All size classes showed very high mortality, with the larger size group having >50% mortality.

Fishing Bay and Honga River

A liberal interpretation of the 1990 distribution indicated three or more year classes (Figure 32), however, some of the peaks probably reflect only sampling variability due to low oyster counts and regional variation. The 1+

year class may have been present at ~50mm and the 2+ year class at ~60-75mm. Mortality was at a low level and relatively uniform over most size classes. In 1991, year class distinction may be more apparent. The 2+ year class grew to a center of ~70mm, and the new 1+ year class appeared at ~55mm. Both of these year classes were showing significant mortality in 1991, unlike the situation in 1990.

Wicomico and Nanticoke Rivers

It is difficult to establish year classes for these regions in both 1990 and 1991. Site and regional variability appeared to mask such distinction. In 1990 the 2+ year class oysters may have had a mode centered at approximately 75mm (Figure 33). Oyster abundance dropped sharply in larger size classes. Mortality was very low for all size classes. In 1991 a similar yet truncated population profile was present. While the bulk of the 1990 population appeared to have shifted to the right due to growth, the high mode of 1990 was absent. Increases in mortality appear to be responsible for this. For oysters ~65mm and larger, the impact of mortality was much greater than in 1990. No great inclusion of a 1+ year class (due to 1990 spat) was visible in 1991.

Potomac River

In 1990, we observed what appeared to be a dominant age group centered at 75mm (Figure 34). Mortality was moderate to high, particularly within the small to medium size classes. Because Potomac River sites vary greatly in salinity and most likely in oyster growth rates, the size distribution probably represented a mixture of year classes.

In 1991, an influx of 1990 spat into the 1+ year class was seen in the 30-60mm group. What may have been the 1990 mode, in general, moved to larger size classes (75-105mm). Extreme mortality occurred for all size classes >50mm.

Patuxent River

In 1990, a small 1+ year class was centered at 50mm and showed minor mortality (Figure 35). The 2+ year class was grouped around 75mm with moderate to heavy mortality. In 1991, both of these year classes had high mortality as well as imperceptibly slow growth rate. Little to no incorporation of 1990 spat into the 1991 1+ year class was apparent.

Individual Site Age Structure

Age class distinction on individual oyster bars was much clearer than for regions. Variations in spatfall and growth rates are presumably less within a single oyster bar than within regional aggregates. Three sites—Choptank River-Tilghman Wharf (CRTW), Tangier Sound-Back Cove (TSBC), and Holland Straits-Holland Straits (HOHO)—were chosen to evaluate whether five 0.2 bushel subsamples were sufficient to describe population size and age structure at a single site. These were the same sites used for analysis of recruitment of spatfall into the population structure (Figure 15). Although the three sites exceeded the means (particularly in box counts) for MFS sites, examination of data from other sites suggested that this effect did not lead to atypical results. At sites where oysters were scarcer, size groupings were still apparent although less abundant.

Size class modes appeared to be distinguishable at each of the sites (Figures 36, 37, 38). Although individual oysters within a year class may exhibit variable growth rate, these peaks probably represent modal sizes of separate year classes. At each site, the large peak of oysters centered between 30 and 60mm should be the 1990 set at approximately 1.2-1.5 years old (summer 1990 to fall 1991, i.e., the 1+ year class). The 2+ year class was apparent in the second peak at both TSBC and CRTW. Older oysters of indeterminate age groups also appeared at these three sites, although age class distinction beyond the 2+ age group was difficult to establish. Although variable yearly growth rates were evident between sites, the rule of thumb for oyster growth in the Chesapeake Bay region (three years to market size, or very roughly 25mm per year) was generally satisfied.

Marked decreases in relative abundance from one year class to the next older were obvious at all three sites. Size structure from all 64 monitored oyster bars indicated that these year class decreases were typical. Harvest was unlikely to be a factor in the reduction of year class abundance with age at these three sites. Available information indicated that none of the above bars were commercially harvested within the previous two to three years (R. Scott, MDNR, pers. comm.). For TSBC, a substantial mortality of the 1+ year class was apparent (about 33%). Reduction in live oyster counts in the 2+ year class from the 1+ year class can largely be attributed to >50% mortality of the 2+ year class. Similar mortality rates were exhibited by the 3+ year class.

At CRTW, the 1+ year class exhibited low mortality. The 2+ year class, however, had close to 75% mortality. A somewhat lower mortality rate was shown by a possible 3+ year class.

The 1+ year class at HOHO exhibited high mortality at sizes above 45mm. It may be questioned whether 1) the size of the oysters was a factor in the higher mortality, or 2) the higher mortality was of an older year class. That is, it might have been a result of mortality in the 2+ year class which died the previous year and still remained as boxes. The surviving 2+ year class grew approximately 20mm, then exhibited very high (75%) mortality during the summer of 1991, which virtually eliminated live oysters of this year class.

Disease

Range and Intensity of Perkinsus marinus *Infection*

Forty-two sites were sampled for disease in 1990. In 1991, 43 sites were sampled—Choptank River-Royston (CRRO) was omitted in 1990. *Perkinsus* distribution and degree of infection were at unprecedented levels and present virtually Baywide in Maryland during both years. Maximum disease intensities for both years generally were found within the lower reaches of Bay tributaries, with somewhat lower intensities in the Bay mainstem. At the lower salinity ranges, the disease was present during both years, but levels of infection were much lower than in higher salinity areas (Figures 39 and 40). Disease statistics on a site by site basis are presented in Appendix C.

Although disease levels differed greatly between sites within a given locale, regional differences were apparent (Figures 41 and 42). The regions were identical to those used

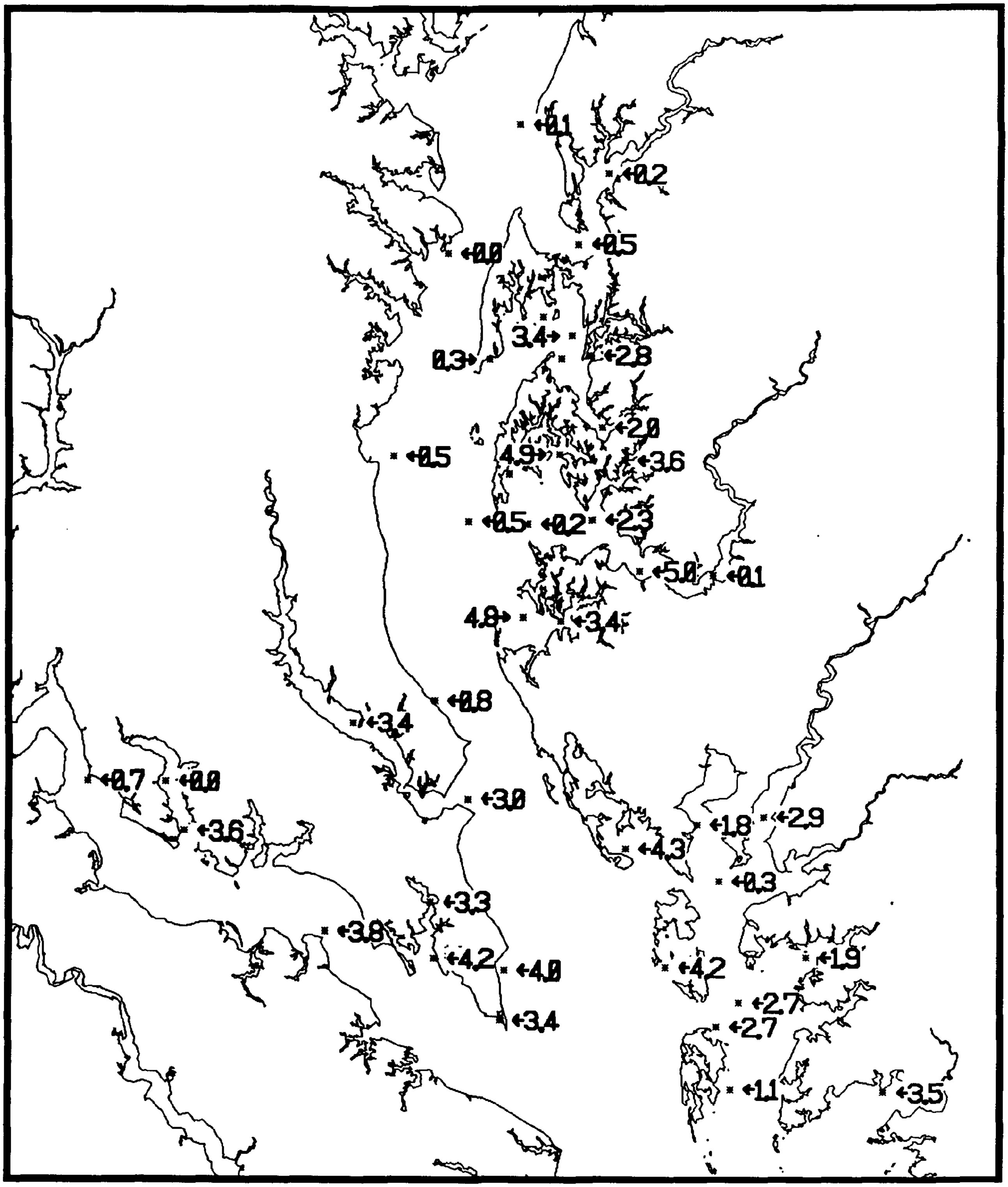

Figure 39. ***Perkinsus marinus*** **intensity index by site, 1990 (rectal thioglycollate diagnosis).**

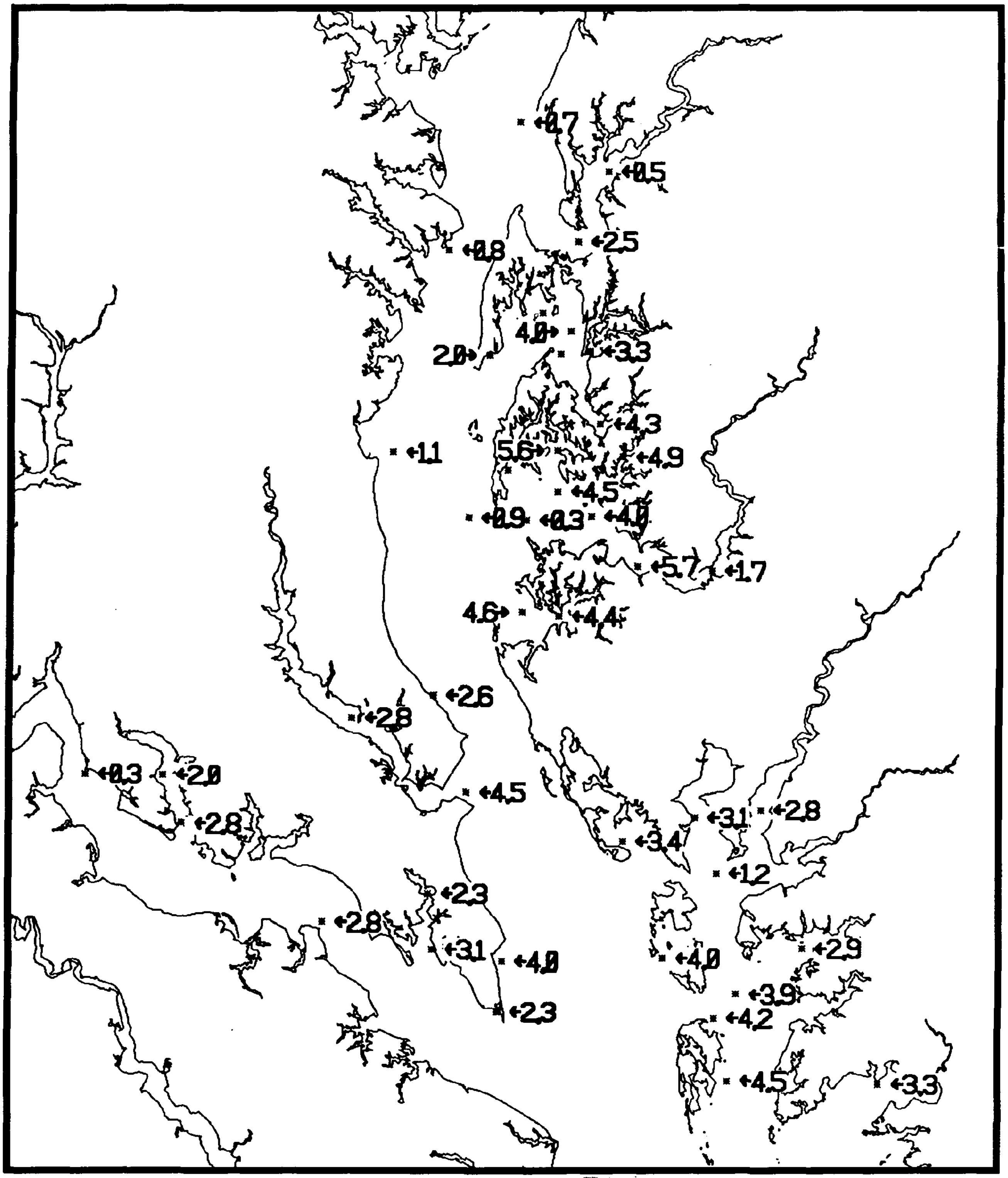

Figure 40. ***Perkinsus marinus*** **intensity index by site, 1991 (rectal thioglycollate diagnosis).**

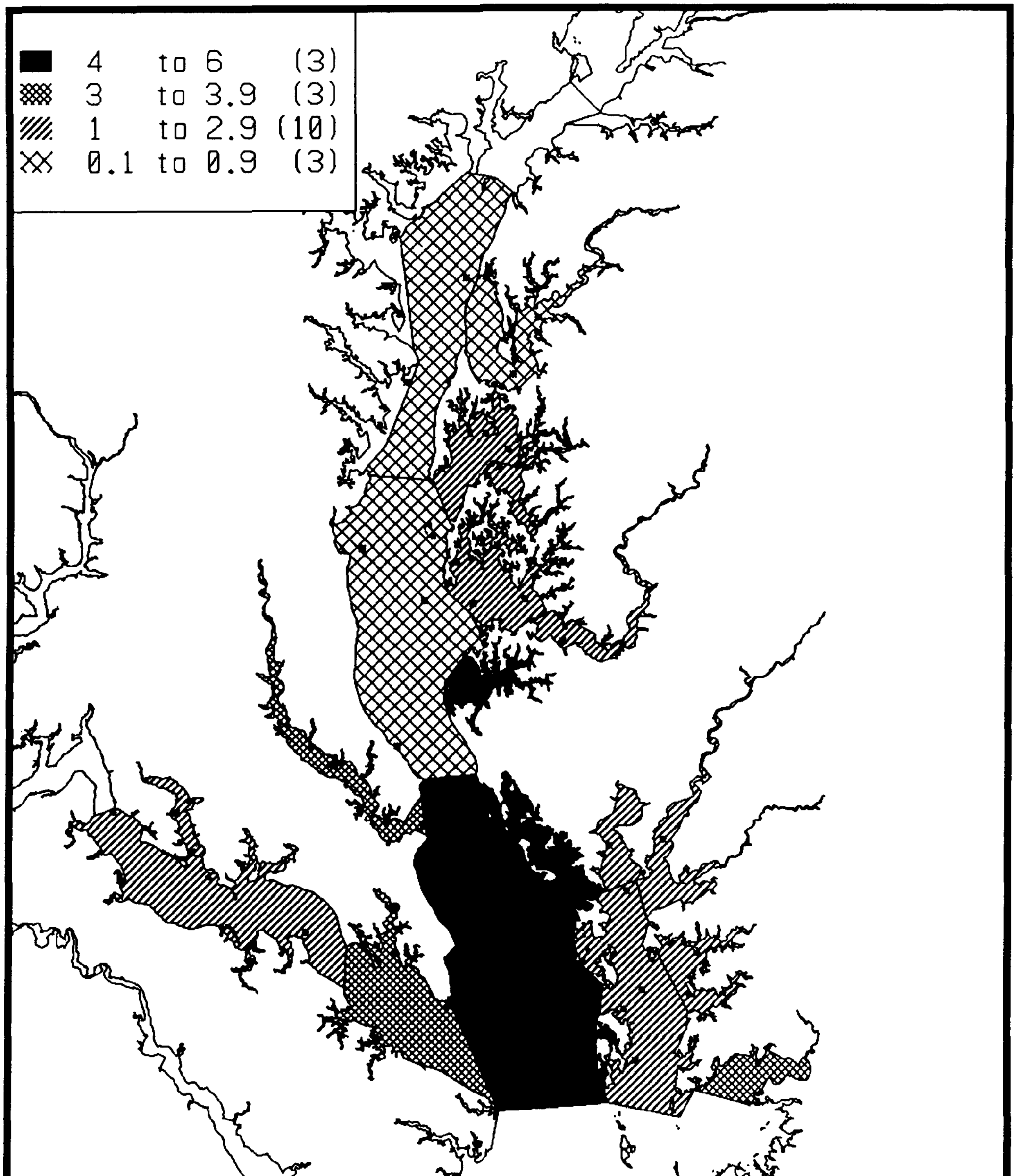

Figure 41. ***Perkinsus marinus*** **intensity index averaged over geographic regions, 1990 (rectal thioglycollate diagnosis). Numbers in parentheses are the number of regions within each range.**

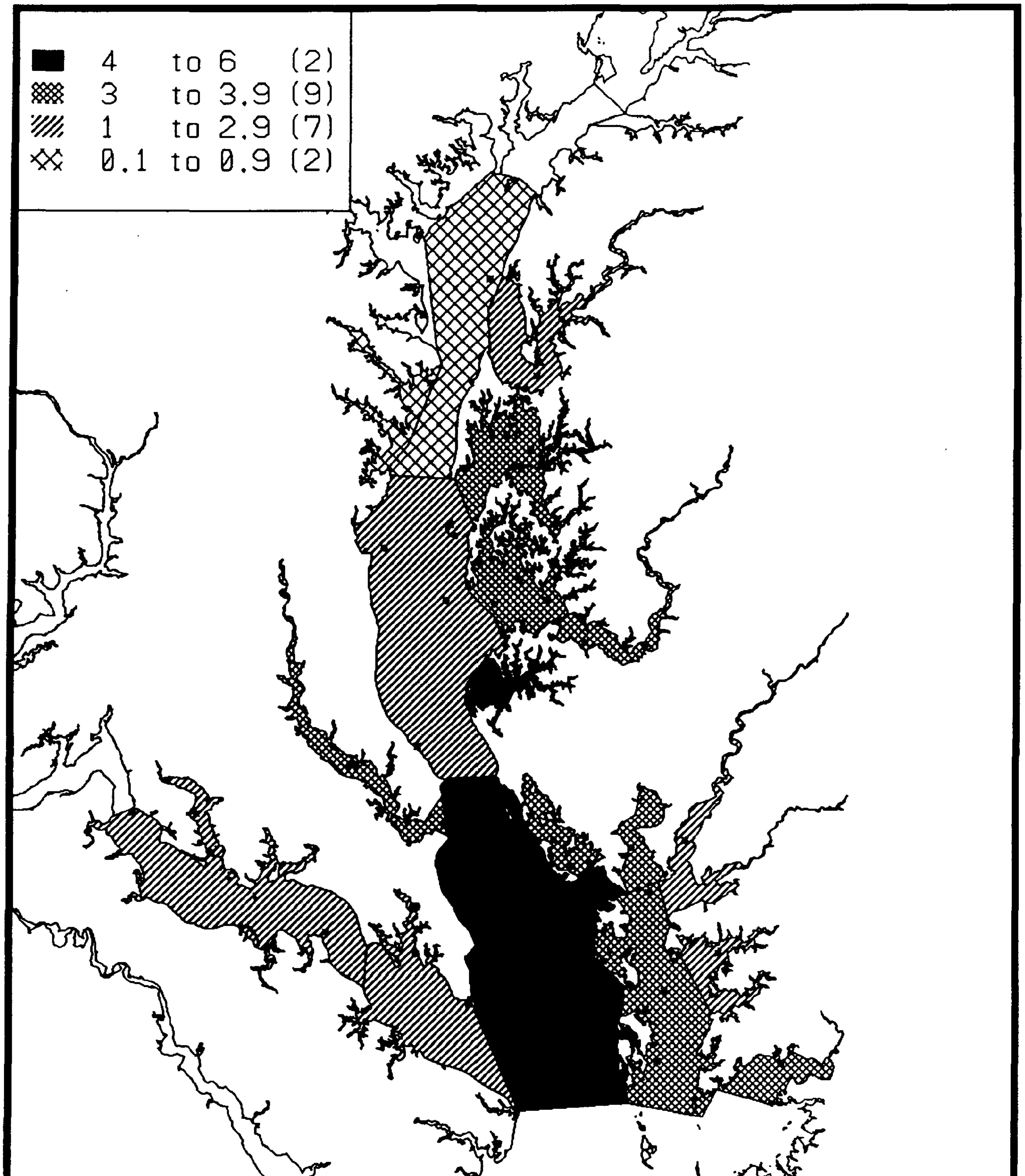

Figure 42. *Perkinsus marinus* intensity index averaged over geographic regions, 1991 (rectal thioglycollate diagnosis). Numbers in parentheses are the number of regions within each range.

to present spatfall and mortality results.

Perkinsus intensity indexes increased from 1990 to 1991. The lower mainstem Bay and Little Choptank regions exhibited severity levels greater than 4.0 for both years. Intensity in the Honga River region appeared to decrease in 1991; however, only one site (HRNO) was diagnosed. Prevalence of 100% was observed in both years, but with a moderate decrease in severity index in the 1991 sample.

The Patuxent and Manokin River regions had high and stable intensity levels during both years. Regions of noticeable *P. marinus* increases were Tangier Sound, Choptank River, Eastern Bay, and the lower Potomac River.

Baywide Changes in Perkinsus marinus, *1990-1991*

The mode of regional intensity increased from <3.0 in 1990 to 3.0-3.9 in 1991 (Figure 43). Likewise, a larger percentage of sites Baywide had higher intensities of *P. marinus* in 1991 (Figure 44); the major difference between 1990 and 1991 was the much smaller number of sites with intensity between 0 and 1.0 in 1991. Intensites in the 5.0-6.0 range were present only in 1991. No sampling sites were free of *P. marinus* disease in 1991.

The mean prevalence of *P. marinus* infections for all sites rose from 68% in 1990 to 83% in 1991 (Table 6). The mean intensity index rose from 2.8 to 3.4. An overall change in oyster meat quality due to this increased infection load was not apparent. Average oyster sizes diagnosed for *P. marinus* analysis were 83mm in 1990 and 85mm in 1991. Oyster sizes sampled Baywide for population statistics were 77mm and 74mm for 1990 and 1991, respectively. Therefore, *P. marinus* statistics generally represented "market" oysters, whereas average survey oyster sizes were close to the 3 in. (76mm) division between smalls and markets.

Evidence for a reduction in *P. marinus* infection pressure within any Bay region from 1990 to 1991 was not found. Only 14 sites had lower *P. marinus* intensity index values in 1991 (Table 7). Twelve of these fourteen sites maintained *P. marinus* prevalences >90% for both years. There was only one site (PRLC) with prevalence less than 90% for both years (40% in 1990, 10% in 1991).

Table 6. Comparison of disease and condition indices, all sites, 1990-1991. Prevalence, severity, and intensity indices are for *Perkinsus marinus*. Only two sites were diagnosed by hemolymph culture in 1991.

	1990	1991
RECTAL THIOGLYCOLLATE CULTURE		
Prevalence (%)	68	83
Severity	2.8	3.4
Intensity	2.3	3.0
BLOOD THIOGLYCOLLATE CULTURE		
Prevalence (%)	65	
Severity	2.7	
Intensity	2.1	
Mean condition	4.4	4.7
Maximum condition	6	6
Minimum condition	3	2
Mean length (mm)[1]	83	85
Maximum length (mm)[1]	108	113
Minimum length (mm)[1]	62	63
Mean length (mm)[2]	77	74
Cliona	5	6
Polydora	35	55

[1]Shell length of oysters diagnosed for *P. marinus*
[2]Shell length of all survey oysters.

Perkinsus intensity was compared across the nine fishery regions (Figure 45) and gave a somewhat different result than for the twenty-one geographic regions. Disease level increases from 1990-1991 were observed in six of the nine regions. Those exhibiting decreases were the Wicomico-Nanticoke, Potomac, and Patuxent regions. The Wicomico-Nanticoke region had data from only one site (NRWS). Potomac data combined sites from the mid- and lower Potomac as well as the St. Mary's and Wicomico Rivers. Decreases in *P. marinus* intensity were apparent at several of these sites (Table 7), but in the majority of cases prevalence was consistently high. The Patuxent River was represented by only one site (PXBI). At this site, although the intensity index decreased slightly, percent prevalence increased to 100%.

Table 7. Sites exhibiting decreasing *P. marinus* intensity indices, 1990-1991. See Table 1 for description of site codes.

Site code	Intensity		Percent	
	1990	1991	1990	1991
LCRP	4.8	4.6	100	100
HRNO	4.3	3.4	100	100
HOHO	4.2	4.0	100	100
SMCC	4.2	3.1	100	97
MRTU	3.8	3.3	100	100
PRRP	3.8	2.8	97	90
WWLA	3.6	2.8	97	97
PSMA	3.5	3.3	97	93
PXBI	3.4	2.8	97	100
PRCH	3.4	2.3	97	83
SMPA	3.3	2.3	93	97
CRTW	3.2	3.0	100	97
NRWS	2.9	2.8	93	100
PRLC	0.7	0.3	40	10

Relationships Among Perkinsus marinus *Indicators*

The *P. marinus* intensity index is used to integrate two components of disease pressure on an oyster bar: 1) disease prevalence (the precentage of oysters infected); and 2) the level or stage of disease within infected oysters (severity index).

In 1991, intensity indexes >2.0 produced percent prevalences of between 90% and 100% (Figure 46). At these intensity levels, the severity index correlated closely with the intensity index—dictated by the fact that at 100% prevalence, the intensity index and severity index are identical (same n in denominator). There was fair association of the intensity index with the percent prevalence at intensities <2. At prevalences below 50% there was no correlation of intensity indexes with severity indexes. That is, at low prevalences, infected oysters could have variable levels of infection.

Rectal thioglycollate diagnosis for *P. marinus* was done for all disease sampling sites for both years. In 1990, blood thioglycollate cultures were done for all but five disease sampling sites. There was a strong correlation of the results for these two methods ($r=0.96$; $p \leq 0.0001$), but marked variation at specific individual sites (Figure 47).

The correlation between *P. marinus* intensity and salinity in 1991 was weak (Figure 48), although traditionally, *P. marinus* has been expected to be more virulent at higher salinities (Andrews 1988). No sampling sites had salinity less than 8 ppt, however. Additionally, salinity at time of the Fall Survey may not have reflected summer-long conditions.

Association of 1991 Spat Densities with Perkinsus marinus

Regions of high 1991 spatfall were also areas of very high *P. marinus* disease pressure (Figure 49). Of the 12 sites with >300 spat per bushel, 10 had intensities >3.0. Percent prevalence at nine of these sites was 100%. At two others, prevalence was 97%. One site (MESR) had only 27% prevalence. This particular site was located in the mainstem of the Bay, generally away from other oyster growing areas.

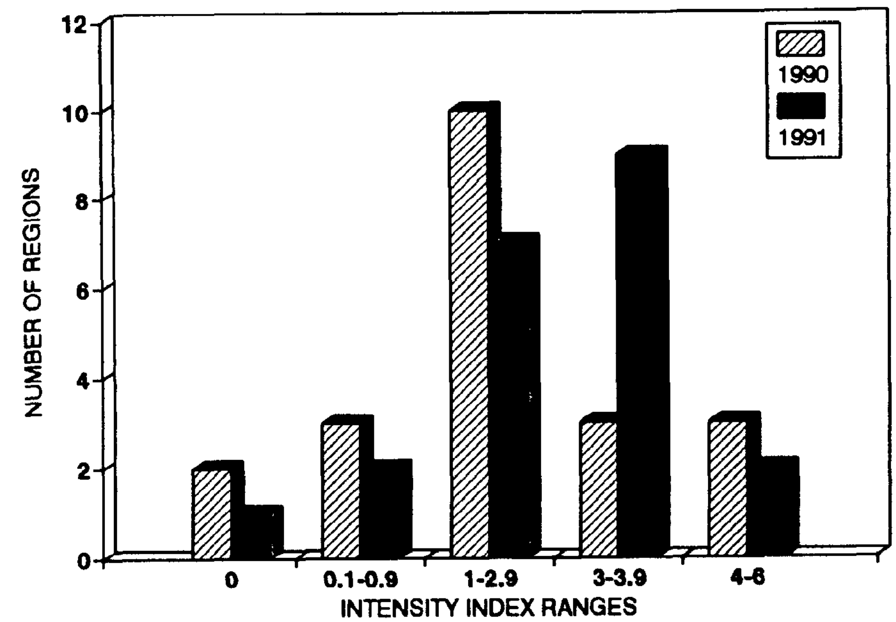

Figure 43. Comparison of ***Perkinsus marinus*** intensity index ranges by geographic regions.

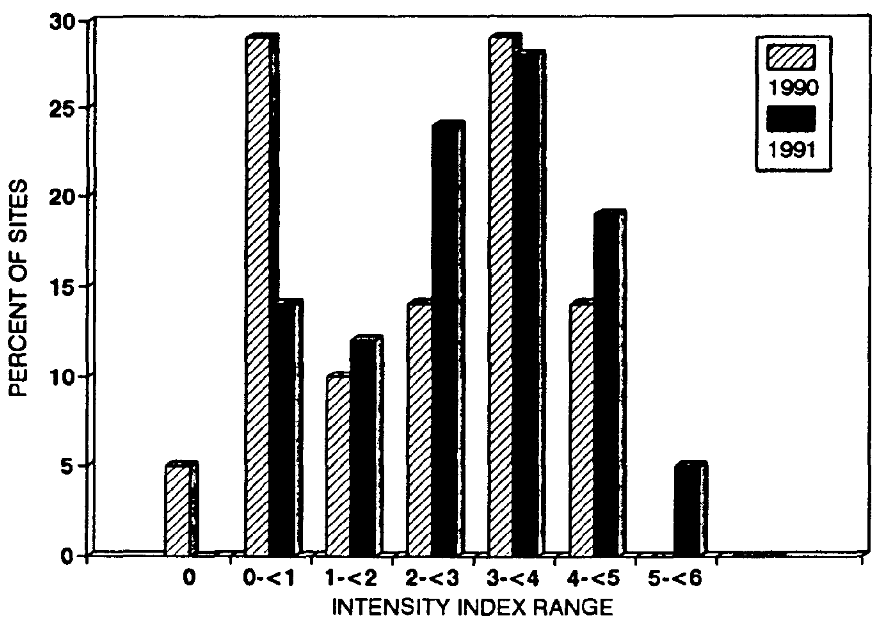

Figure 44. Comparison of ***Perkinsus marinus*** intensity index ranges by sites.

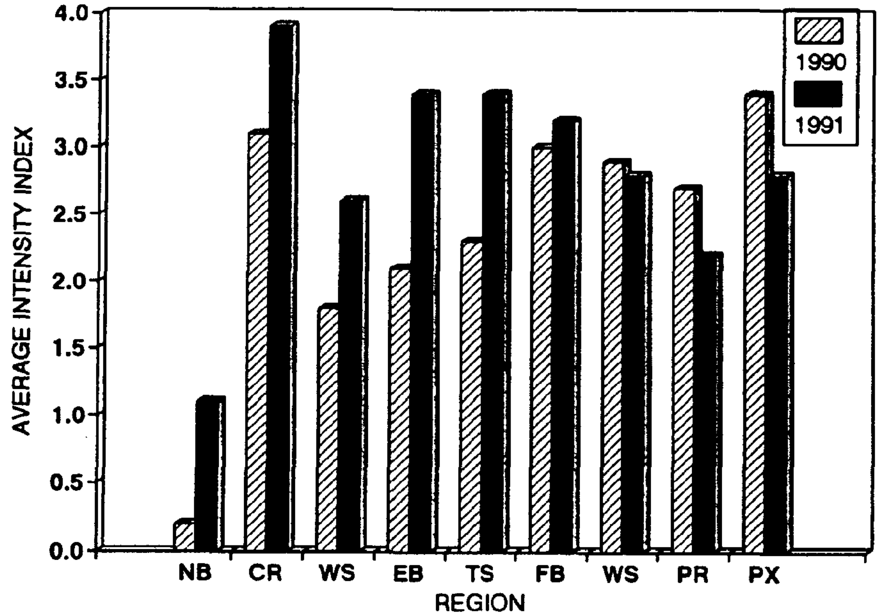

Figure 45. ***Perkinsus marinus*** **intensity index averaged by harvest regions.**

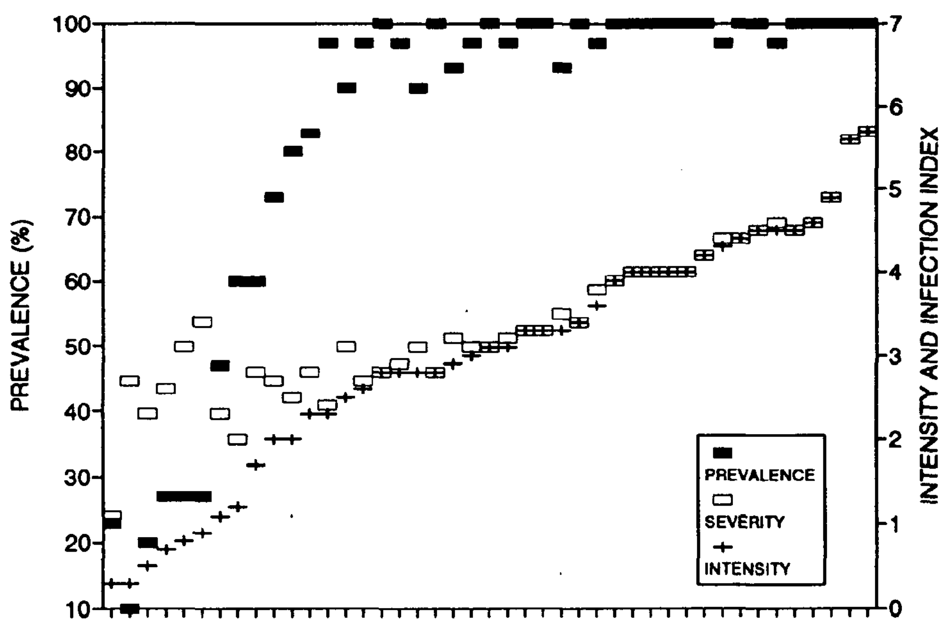

Figure 46. Comparison of ***Perkinsus marinus*** **indices from all sites, 1990 and 1991.**

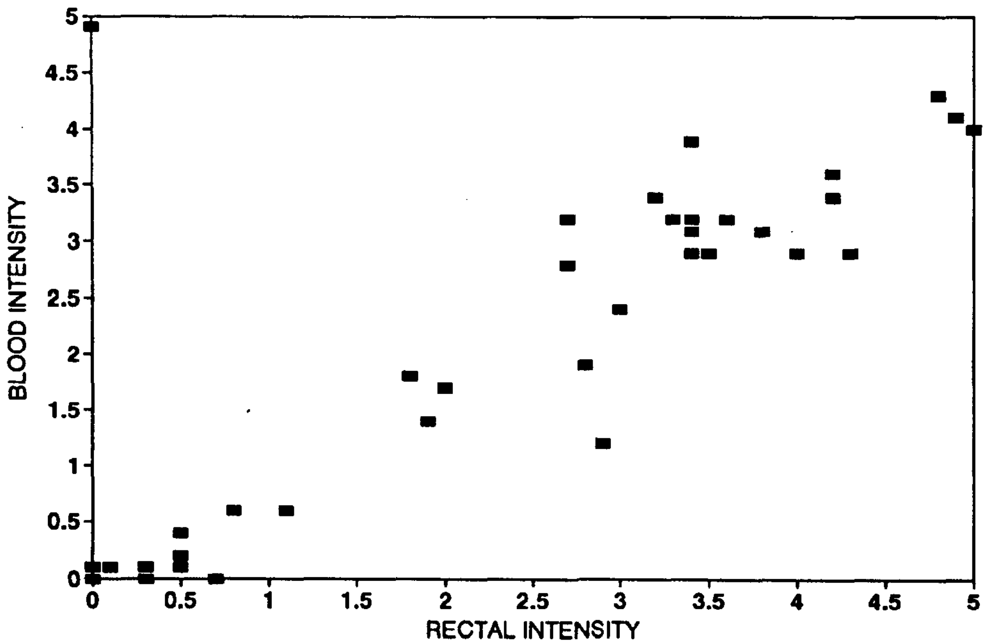

Figure 47. Comparison of *Perkinsus marinus* rectal and hemolymph (blood) diagnostic methods from sites where both methods were applied to the same sample, 1990 and 1991.

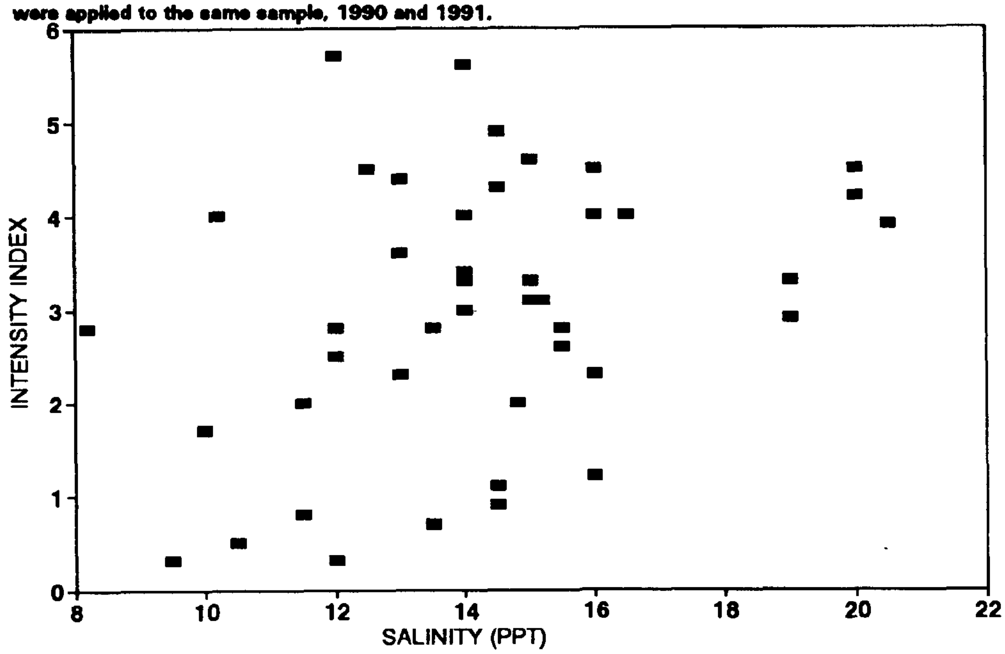

Figure 48. *Perkinsus marinus* intensity as a function of salinity at the time of sampling, 1990 and 1991.

Table 8. Modified Fall Survey oyster bars with presumed harvest activity, 1990-1991. C. Judy, R. Scott, and G. Krantz, Maryland Department of Natural Resources, pers. comm.

Site	Region	Oyster bar
BNMP	Bay Bridge North	Mountain Point
BNSP		Swan Point
CHBR	Chester River	Buoy Rock
CHOF		Old Field
CROS	Choptank River	Oyster Shell Point
EBHN	Eastern Bay	Hollicutts Noose
FBGC	Fishing Bay	Goose Creek
MESR	Mid Eastern Shore	Stone Rock
NRWE	Nanticoke River	Wetipiquin
NRWS		Wilson Shoal
PRLC	Potomac River	Cedar Point
PXBA	Patuxent River	Back of Island
UBHA	Upper Bay	Hacketts
UBTS		Three Sisters
WRMV	Wicomico River	Mt. Vernon Wharf
WSBU	Western Shore	Butler
WSFP		Flag Pond
WSHI	Western Shore	Hog Island
WSHP		Holland Point
WWLA	Wicomico West	Lancaster
WWMW		Mills West

Association of Perkinsus marinus *Intensity with Mortality*

There was a strong positive correlation ($r^2 = 0.75$, $p<0.0001$) between 1991 oyster mortality and *P. marinus* intensity (Figure 50). At intensities below 1.0, mortality was consistently below 10%. Greater variation was shown by oyster bars with an intensity index ≥4.0; on these bars, mortality ranged from 25-95%.

The relationship between *P. marinus* intensity and mortality was similar for 1990 and 1991 (Figure 51). Mortality, intensity, and prevalence all increased in rough proportion from 1990 to 1991.

Reappearance of Haplosporidium nelsoni *in Maryland*

Analysis at selected sites for the appearance of *H. nelsoni* disease indicated a resurgence of this disease in the lower Maryland Bay in 1990. Although relatively few sites were selected for this analysis, intensity indexes up to 0.4 were observed in the Tangier Sound region (Figure 52). Maximum prevalence for this disease was 20%.

In 1991, the range and intensity of *H. nelsoni* increased in the Tangier Sound region (Figure 53). The parasite also was found in the Little Choptank and Choptank Rivers, and to a lesser extent in Eastern Bay. Maximum intensities for *H. nelsoni* in 1991 were 0.5, associated with prevalences of 20%.

Two analysis techniques were used for the determination of *H. nelsoni* disease level in 1990 and 1991: blood histocytology and histology of tissue sections. The results shown in Figures 52 and 53 are a mixture of the two methods. In cases where techniques were duplicated, the method that gave the higher intensity index is represented.

Harvest

Harvested Oyster Bar Identification

Of the 64 MFS oyster bars, 21 (33%) were characterized as harvested or productive for the purposes of this report (Table 8). The list was compiled with the aid of Maryland Department of Natural Resources personnel who identified MFS oyster bars that had had harvest activity, based upon overflight or research vessel observations. The two harvest seasons, 1990-1991 and 1991-1992, were not separated; all oyster bars on this list were considered as "harvest bars" throughout the two seasons. For interpretive purposes, it should be noted that many productive oyster bars were not represented on this listing, because they were not included in the MFS.

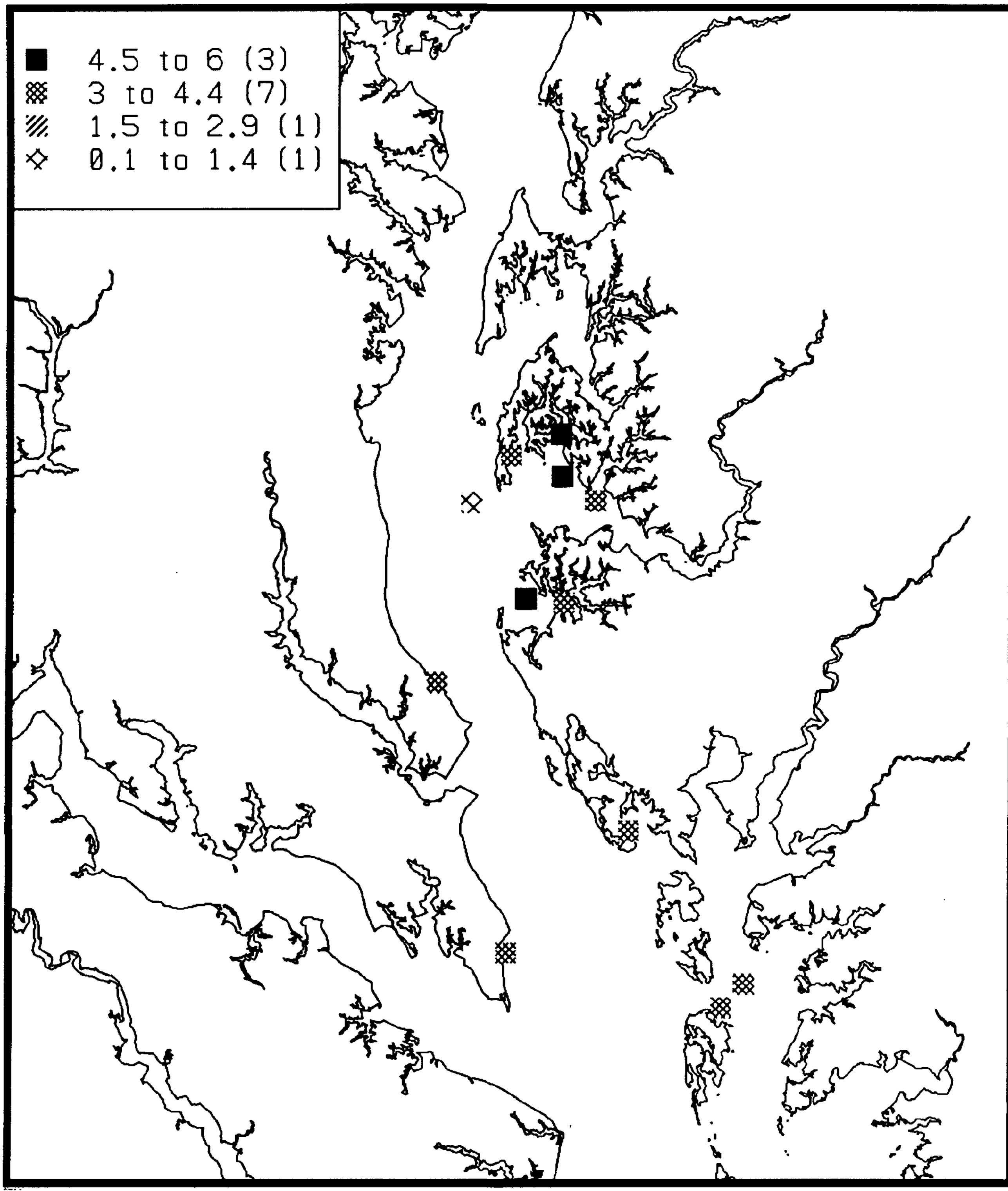

Figure 49. *Perkinsus marinus* intensity at sites with spat counts greater than 300 per bushel, 1991.

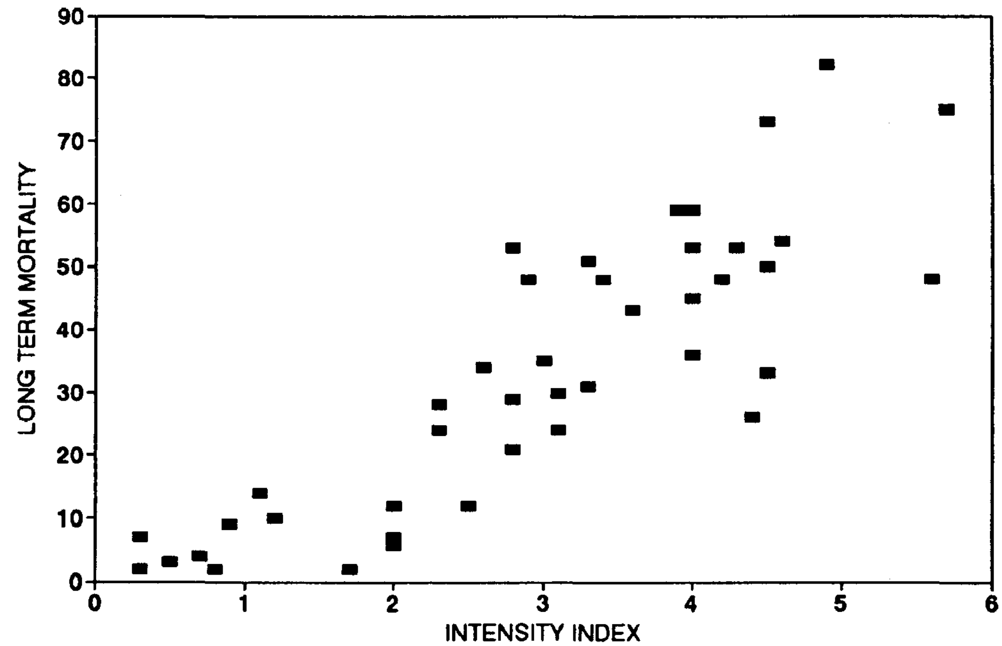

Figure 50. Correlation of oyster mortality with *Perkinsus marinus* intensity, 1990 and 1991; r=0.88; p<0.0001.

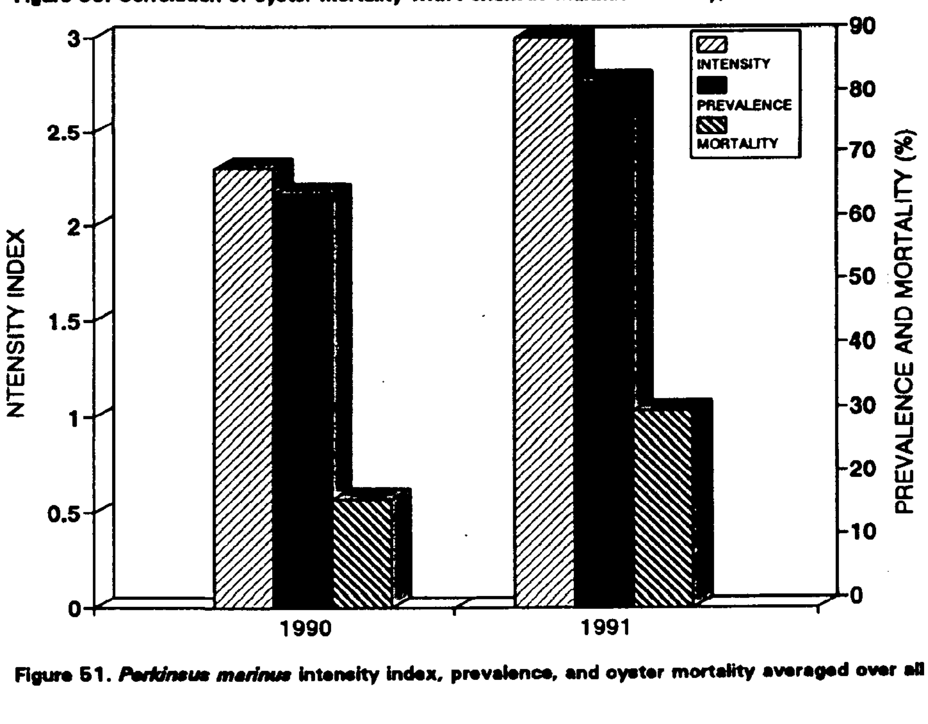

Figure 51. *Perkinsus marinus* intensity index, prevalence, and oyster mortality averaged over all sites.

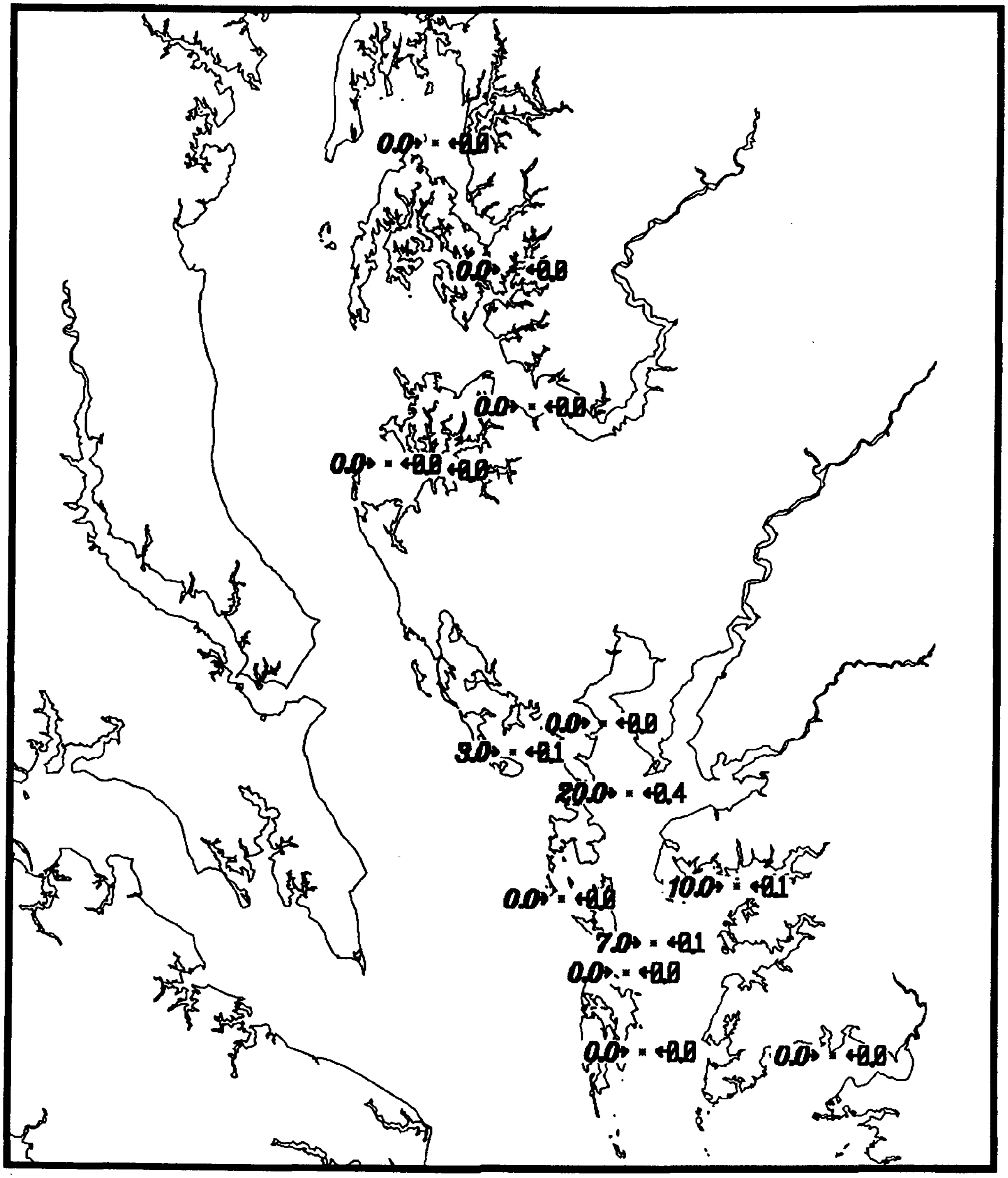

Figure 52. ***Haplosporidium nelsoni*** **prevalence (bold italic numerals) and intensity, 1990. All sites sampled are shown.**

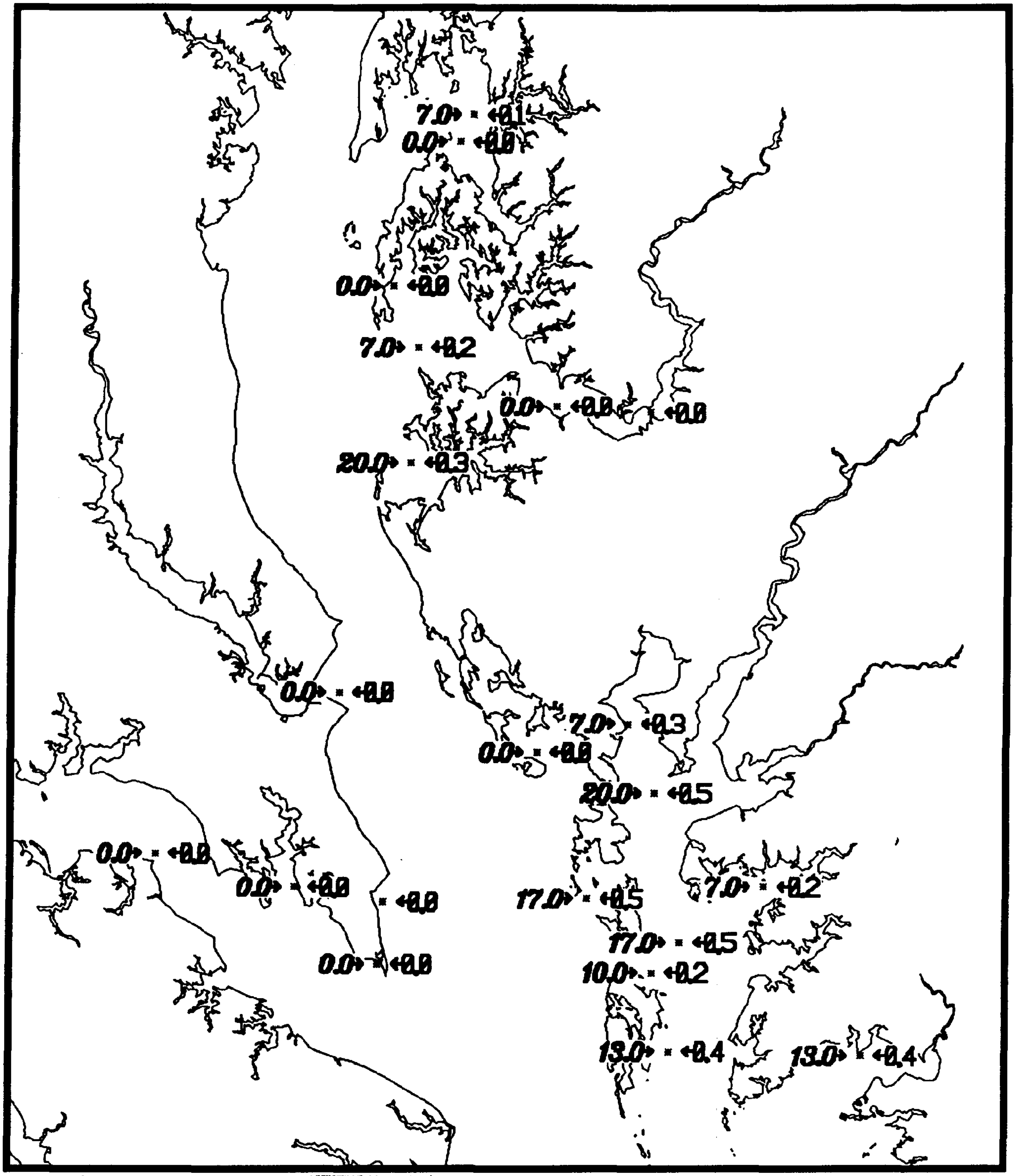

Figure 53. ***Haplosporidium nelsoni*** **prevalence (bold italic numerals) and intensity, 1991. All sites sampled are shown.**

Six of the 21 MFS bars designated as harvest bars were located in the northern portions of the Bay. Another four were along the mid-western shore of the Bay. Together these two regions comprised roughly half (10) of the harvest bars sampled. Noticeably absent in the harvest bar listing were many sites in Tangier Sound, the Choptank River, the Potomac River, and Eastern Bay. Together these traditional oyster production regions contribute only three sites to the list of harvest survey bars.

Comparison of Harvested Oyster Bars to All MFS Bars

Although these oyster bars may not have fully represented where harvest activity was centered during the 1989-1990 and 1990-1991 oyster seasons, comparison of the harvested bars against non-harvested oyster bars for 1990 and 1991 showed distinct differences (Table 9). Oysters were more abundant per bushel of substrate on harvested oyster bars, with harvested bars having 2-3 times as many market oysters as non-harvested bars. Predominance of small (<3 in.) oysters was not so marked on harvested oyster bars. This distinction was strongly reflected in small:market ratios. On harvested bars, ratios were near 1:1 for both years. On non-harvested bars, the ratios were 1.6:1 (1990) and 2.0:1 (1991). The relatively lower number of small oysters could have had a relationship to spatfall. Non-harvested oyster bars showed a significantly higher level of spatfall for both sampling years. The preponderance of harvested bars in traditionally low spatfall areas must, however, be considered in this relationship.

Of the 64 MFS oyster bars, 15 were subjected to recent (within 3 years) seeding. Of the 21 harvest bars, 9 (43%) were subjected to recent seeding. The effect of seed on population structure could not be determined for the harvest bars as a group.

Differential effects of disease and mortality on harvested and non-harvested bars were apparent. Long-term total mortality for non-harvested bars was 22% in 1990 and 38% in 1991. Harvested bar mortality was 8% in 1990 and 18% in 1991 (Table 9). *Perkinsus* prevalence for non-harvested bars was 85% (1990) and 94% (1991). For harvested bars, these values were 41% and 66%. *Perkinsus* intensity index values for non-harvested bars were 3.3 (1990) and 3.7 (1991). Harvest bar intensities were 1.9 (1990) and 3.0 (1991).

Table 9. Comparison of harvested and non-harvested oyster bars, 1990-1991. Values are averaged over 42 oyster bars ("non-harvested") or 21 bars ("harvested").

	Non-harvested		Harvested	
	1990	1991	1990	1991
Counts				
Live	84	71	121	119
Markets	32	23	62	61
Smalls	52	47	59	59
Small:market	1.63	2.04	0.95	0.96
Mortality (%)				
Total	22	38	8	18
Markets	26	48	8	19
Smalls	20	29	9	18
Shell height (mm)				
All	76	71	79	79
Markets	86	87	88	91
Smalls	62	54	66	59
Perkinsus marinus				
Prevalence (%)	85	94	41	66
Severity index	3.3	3.7	1.9	3.0
Intensity index	3.0	3.6	1.2	2.0
Spat per bushel	62	27	47	93
Meat condition[1]	4.2	4.3	4.7	5.3

[1]4 = medium minus; 5 = medium plus.

In general, harvested bars exhibited <30% mortality and *P. marinus* intensity <3.0 (Figure 54). Two harvest bars on the Western Shore—Hog Island (WSHI) and Butlers (WSBU)—did, however, exhibit mortality >50% and intensity >4.0.

Two non-harvest bars had low mortality (<15%) and intensity (<1.5). The lack of harvest activity on these bars apparently was not related to disease and mortality. They simply did not have enough market oysters per volume of substrate (<25 per bushel of substrate) for practical harvesting. The majority of non-harvested bars had *P. marinus* intensity >3.0 and mortalities >30%.

There was an apparent trend toward a lower density of market oysters with increasing *P. marinus* intensity (Figure 55). Non-harvested bars all had <65 market oysters per bushel of sample substrate. There was not strong correlation between number of market oysters and *P. marinus* intensity for either harvested ($r=-0.32$; $p=0.23$) or non-harvested ($r=-0.21$; $p=0.28$) oyster bars. Harvested bars, in general, had >40 market oysters per bushel. Oyster bars with *P. marinus* intensity <2.0, combined with a sufficient density of market oysters, were certain to be harvested.

A view of population profiles for harvested oyster bars in 1990 and 1991 indicated some differences. In both years, peak size class abundance was ~75-80mm (Figures 56 and 57). Mortality, however, was greater on the harvested bars in 1991 than in 1990. The total number of market oysters decreased slightly in 1991.

The population of oysters on harvested bars was similar in size structure to the composite of all MFS bars in 1990 (compare Figures 24 and 56) In 1991, this structural similarity was no longer apparent (Figures 25 and 57). Harvest bars, while showing increased mortality throughout all size ranges, still exhibited a normally distributed population size structure. The composite of MFS bars, both harvested and non-harvested, exhibited strong erosion of this structure due to mortality in the 50-80mm range. Likewise, a much higher proportion of larger size classes was dead on the MFS bars in 1991.

Although MFS harvest bars may not have been reflective of fishing effort (only the presence of harvest activity) in a regional sense, aggregation into five generalized regions provided some insight (Figures 58-62). In 1990 the Northern Bay and Chester River regions had population profiles very similar to that of all 1990 harvest sites (Figure 58). In 1991, the population profile separated into two major size class modes. The mode centered at 60mm was related, to a large extent, to introduction and growth of transplanted seed oysters, as spatfall was low in northern regions in 1990. The second mode, centered at 90mm, was most likely the yearly carryover of the 1990 central mode. A slight decrease in oyster numbers was apparent, as well as the beginning of apparent mortalities. There was some overall growth of this grouping of oysters, as seen by a slight rightward shift of the peak to a larger size.

Harvested bars in 1990 in the mid-Eastern Shore region likewise showed the same narrow, highly pronounced central mode of oyster size structure (Figure 59). Again, the peak was centered at 75mm (3.0 in.). In 1991, a very similar peak was present at the same location. Incorporation of last year's spat/seed can be seen centered at 45mm. Of note on these harvested oyster bars is the almost total lack of mortality (as compared to the high mortalities previously shown for all MFS bars in this general region).

Maryland Western Shore harvested oyster bars in 1990 again showed the characteristic profile for harvest bars (Figure 60). The large central population mode was centered at 67mm. Mortality was high within this mode. In 1991, the effects of mortality due to disease were dramatic. Although growth was exhibited, as shown by a general shift to the right by the population, the principal mode of population abundance of 1990 was removed due to mortality and or harvest. The high mortality centered at 75mm may, in fact, have been early-dying remnants of the oysters which grew from a central peak of 75mm in 1990 to a central peak of 90mm in 1991.

The lower Eastern Shore in 1990 exhibited a population mode at 70-75mm (Figure 61). The effect of mortality on these harvested bars was negligible. In 1991, the impact of mortality was more pronounced on larger oysters. The total number of oysters collected in the sample was lower, due to the mortality within the 1990 mode of oyster abundance. Little apparent recruitment from the previous year's spat was apparent.

Harvest bars within the Potomac and Patuxent systems exhibited a narrow population structure in 1990 (Figure 62). The population mode was centered at 75mm. This size class showed apparent overall growth to a central peak of 90mm in 1991, but also showed a great increase in mortality for 1991. The density of oysters per volume of substrate was lower by nearly half in 1991.

Estimation of Harvest Mortality

Our estimate of annual (1990-1991) harvest mortality on harvested oyster bars included within the MFS was 53%. This value was obtained by;

1) Numerically subjecting the 1990 live oyster population on these oyster bars to average 1991 harvest bar mortality (18%). Comparison of the projected natural mortality to the 1991 actual mortality (box counts) showed strong similarity in the size and shape of both distributions (Figure 63). Variations between sampling years in live oyster counts due to seeding were apparent in the 37-67mm size classes.

2) After adjusting the 1990 live oyster population for natural (including disease) mortality, live oyster counts for each 5mm size class were adjusted upward 20mm to reflect growth between annual sampling periods. The difference between 1991 actual live counts of oysters over 85mm and live counts predicted by the above calculations produced the estimated harvest mortality (Figure 64).

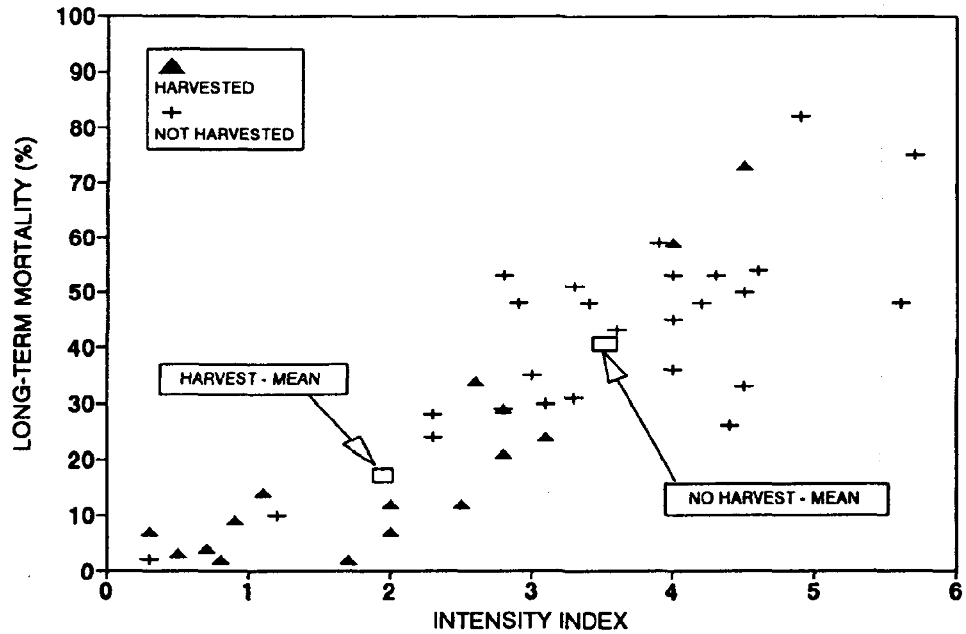

Figure 54. Correlation of oyster mortality with *Perkinsus marinus* intensity on harvested and unharvested oyster bars, 1991.

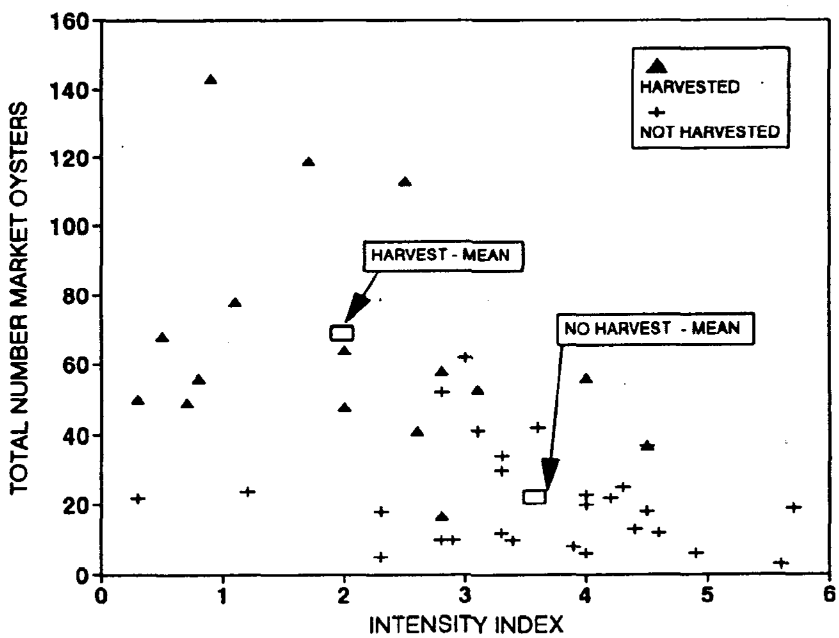

Figure 55. Comparison of market oyster density (counts per bushel of substrate) with *Perkinsus marinus* intensity on harvested and unharvested oyster bars, 1991.

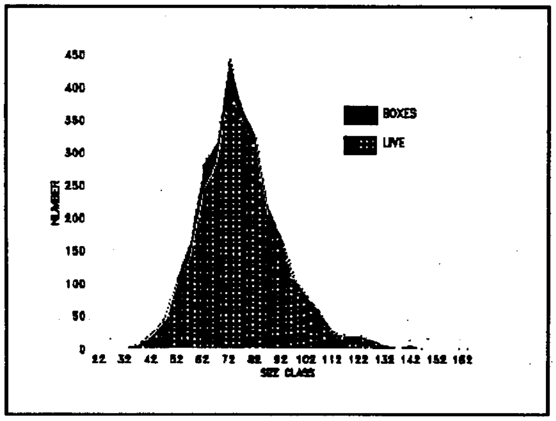

Figure 56. Harvested oyster bars population structure, baywide, 1990.

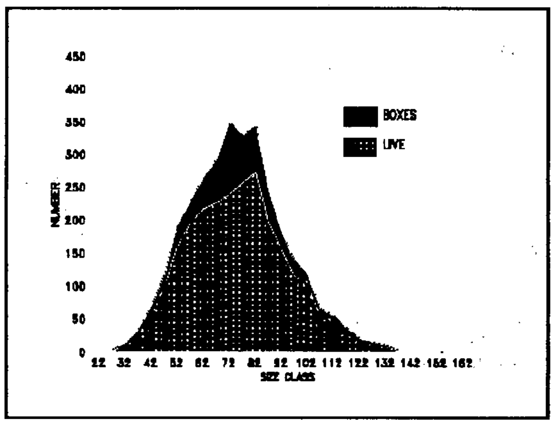

Figure 57. Harvested oyster bar population structure, baywide, 1991.

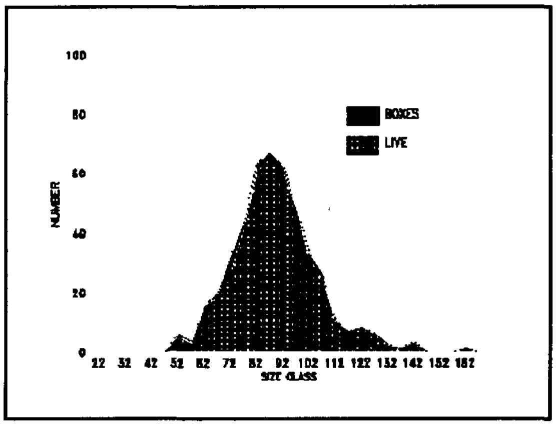

Figure 58a. Harvested oyster bar population structure by component; Northern Bay, Chester River regions, 1990.

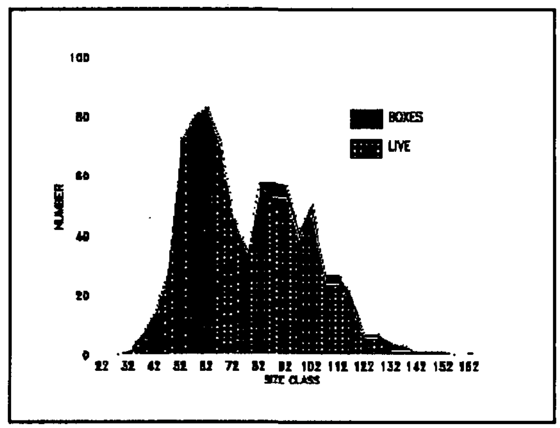

Figure 58b. Harvested oyster bar population structure by component; Northern Bay, Chester River regions, 1991.

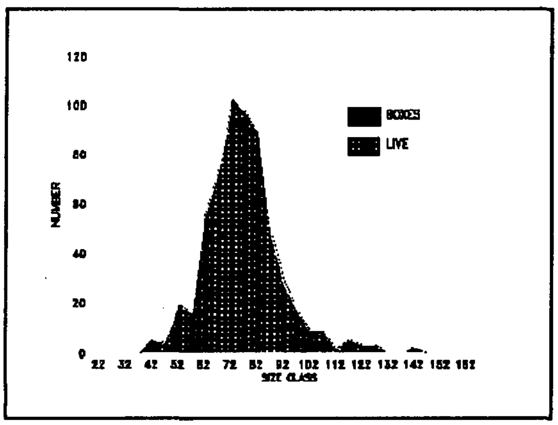

Figure 59a. Harvested oyster bar population structure by component; Mid Eastern Shore, Choptank River regions, 1990.

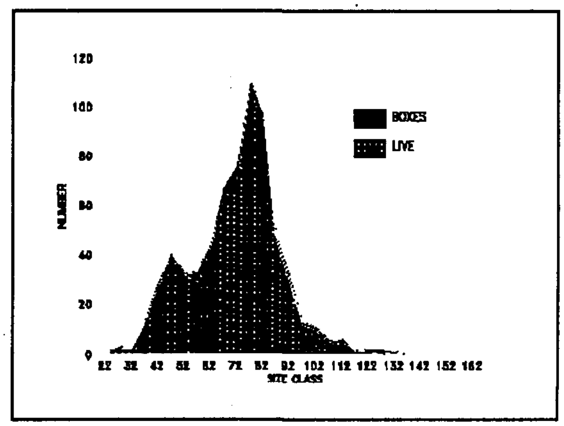

Figure 59b. Harvested oyster bar population structure by component; Mid Eastern Shore, Choptank River regions, 1991.

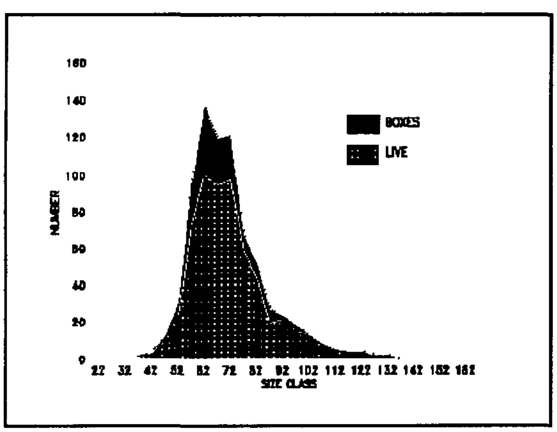

Figure 60a. Harvested oyster bar population structure by component; Western Shore region, 1990.

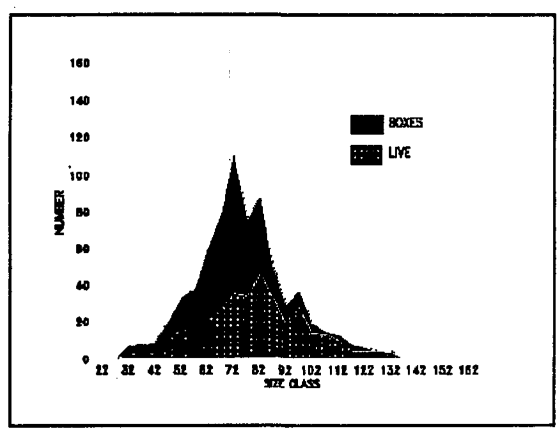

Figure 60b. Harvested oystre bar population structure by component; Western Shore region, 1991.

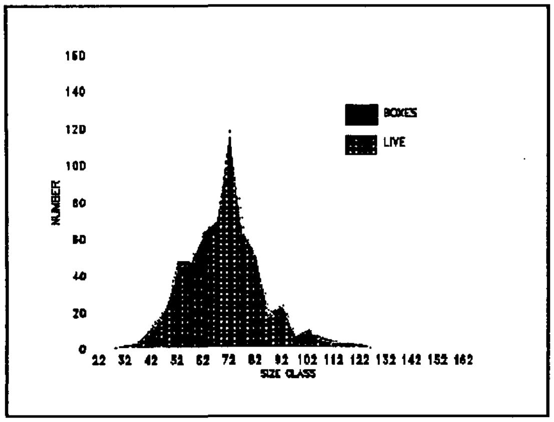

Figure 61a. Harvested oyster bar population structure by component; Lower Eastern Shore region, 1990.

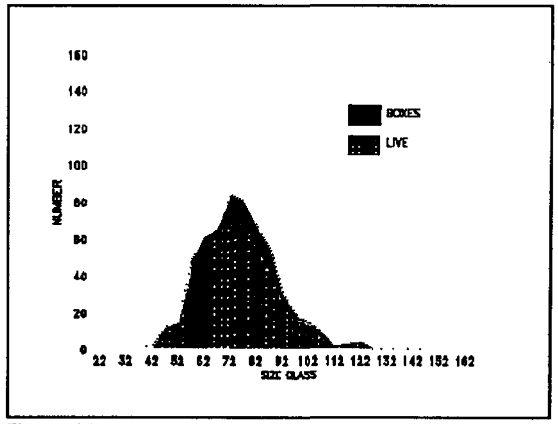

Figure 61b. Harvested oyster bar population structure by component; Lower Eastern Shore region, 1991.

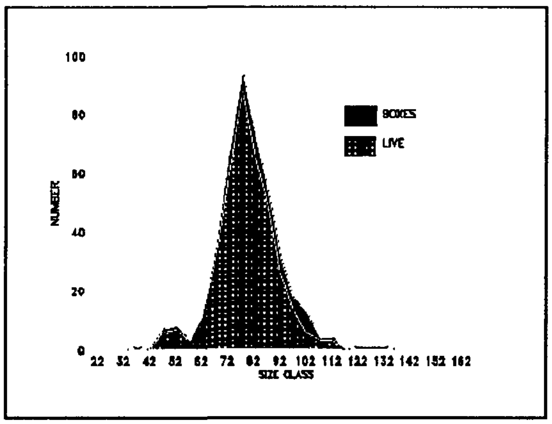

Figure 62a. Harvested oyster bar population structure by component; Potomac River, Patuxent River regions, 1990.

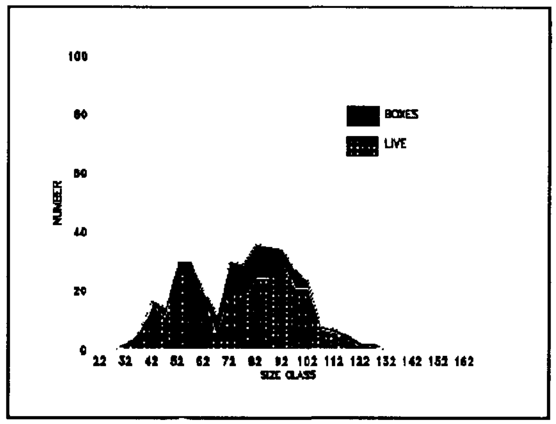

Figure 62b. Harvested oyster bar population structure by component; Potomac River, Patuxent River regions, 1991.

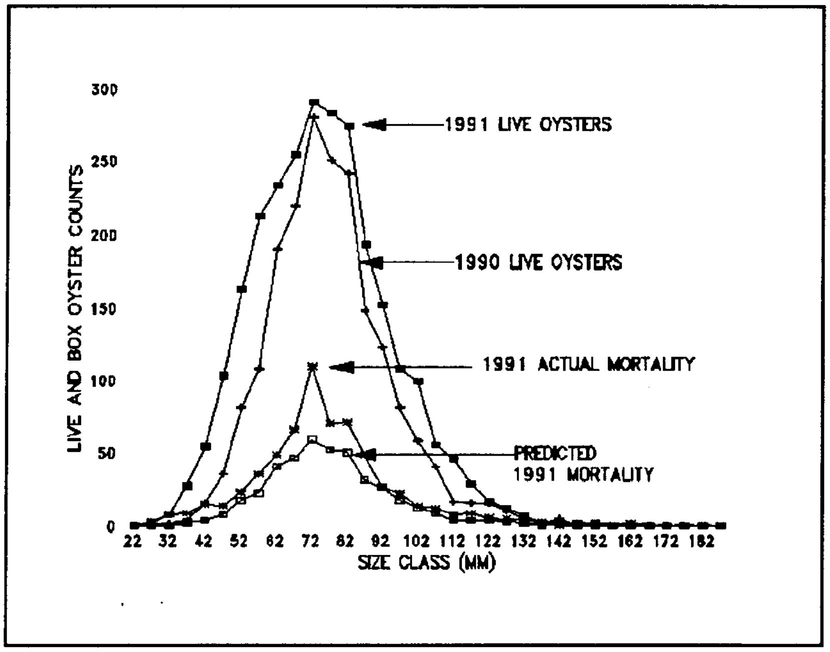

Figure 63. Comparison of 1990 harvested bars live oyster population structure subjected to a simulated 18% mortality to actual harvested bars 1991 live oyster counts.

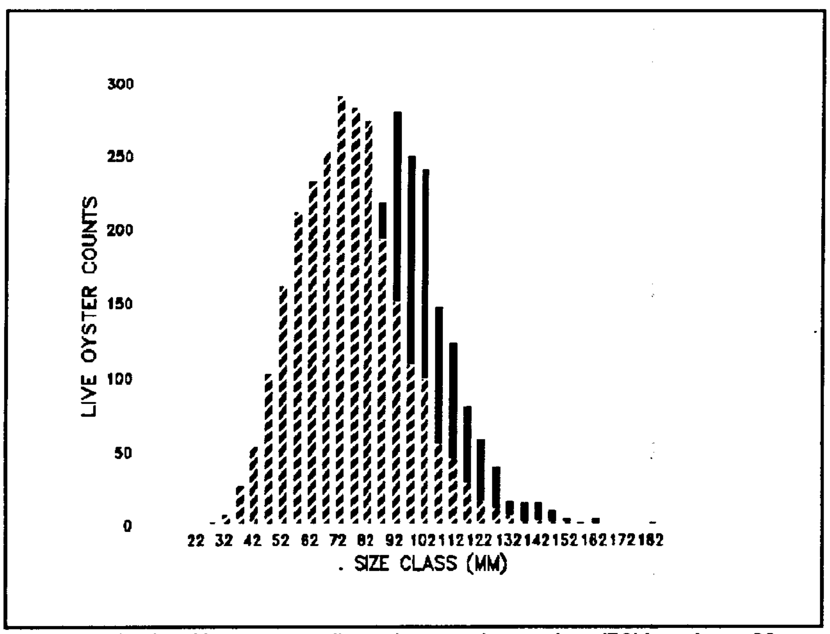

Figure 64. Simulated harvest mortality on harvested oyster bars (53) based on a 20 mm. grow out of the 1990 live oyster population (Figure 61).

IV. DISCUSSION

Synopsis of Oyster Population Results

Impact of Disease

The MFS results suggest that parasitic infections had the most important impacts on oyster populations between 1990 and 1991. Although both *P. marinus* and *H. nelsoni* have been responsible for oyster mortalities in Chesapeake Bay since at least the 1950's (Kennedy and Breisch 1981; Andrews 1988), the current level of *P. marinus* disease in Maryland waters is unprecedented. *Perkinsus* and *H. nelsoni* are both microscopic protozoan parasites with multiple life stages. *Perkinsus* is strongly influenced by temperature, exhibiting near dormancy in winter (Andrews 1988). The prevalence and virulence of *H. nelsoni* are largely related to salinity. High salinity can increase the virulence and spread of the disease whereas lower salinities can eradicate it (Haskin and Andrews 1988).

Perkinsus and *H. nelsoni* historically have had different patterns of mortality in oysters. When epizootic, *H. nelsoni* can kill oysters throughout the summer after initial spring infections. Springtime mortalities due to *H. nelsoni* also may be caused by overwintering dormant infections. There appear to be interactions among temperature, salinity, and possibly other controlling factors that affect the dynamics of *H. nelsoni* infection and lethality (Haskin and Andrews 1988). The methods for numerical staging of *H. nelsoni* and *P. marinus* are similar, but laboratory observations suggest that *H. nelsoni* can cause higher oyster mortalities at lower diagnostic intensities.

Perkinsus has historically been characterized as a progressive, slowly killing disease. It may take up to three years after initial infection to cause death in an oyster, although death in the second summer is typical (Andrews 1988). High mortalities were exhibited by 1+ and 2+ year classes in the 1990 and 1991 MFS. High mortalities in the 1+ year class at some sampling sites may have been caused by *H. nelsoni* or *H. nelsoni* in combination with *P. marinus* (many sites were not analyzed for *H. nelsoni*).

An adage of some significance to the current harvest situation is that an oyster takes three years to grow to a marketable size (76mm or 3 in.). Results from selected sampling sites and regional aggregations of sites support this assumption. Despite small differences in growth rate, the putative 2+ year class generally was centered near 76mm. These oysters would have settled in the summers of 1988 (1990 survey) and 1989 (1991 survey), giving them roughly 2½ growing seasons to approach market size. Some of these oysters would have entered the fishery during the fall and winter of the survey, whereas others presumably would not have reached legal size until the following harvest season.

The highest mortality of oysters was occurring in the size class that was just entering the fishery. Thus, just as oysters were approaching a marketable size, they were dying at their fastest rate. Most of these mortalities were attributable to *P. marinus*. Also, heavily infected populations virtually ceased to grow. This effect has been documented in experimental work (Paynter and Mallonee 1990), and the MFS results clearly showed the effect of this growth impairment on natural populations. Perhaps the clearest example of this was at Patuxent River sites between 1990 and 1991 (see Figure 35). The 2+ year class of 1990, which was showing the beginnings of high mortality, grew an average of only about 10mm to the 3+ year class in 1991.

Parasite-induced mortalities and reduced growth have important implications for harvest production. At the same time oysters are approaching market size, they experience their highest mortalities; and because their growth is stalled, in effect they are subjected to increased risk of mortality before they are large enough to be harvested. A small increase in the time oysters remain disease-free in the early life stages would greatly increase their chance of survival to market size. The combination of massive mortality in the 2+ year class and growth inhibition caused by *P. marinus* indicates that if oysters were given a six month head start free from *Perkinsus* disease, they could survive to a marketable size. Rearing oysters in a disease-free aquaculture environment for 6-12 months, followed by placement on natural oyster bars, is a potential stock enhancement method. An alternative method would be immediate movement of seed to low salinity areas prior to initial infections during the summer disease season. Whatever oyster movement scenarios were employed, the objective in managing around *P. marinus* is to remove spat early from disease-prone areas. There are two reasons, however, why these schemes might not contribute to a significant increase in adult stocks or harvests. First, both hatchery rearing and seed movement are expensive, and subject to failure for various reasons unrelated to disease. Second, movement of seed from areas with severe disease problems risks introducing or increasing the prevalence of parasites in areas where they are not abundant (Andrews 1988).

Mortality as estimated by box counts does not show its full impact (due to disease or other causes) on an age class. An underlying assumption of these estimates is that boxes do not remain articulated for more than one year. Box counts largely reflect an annual, or more specifically summer-long mortality, so they do not indicate mortality of the age group in previous years. Although age groups vary from year to year in abundance as they enter the 1+ year class, obvious declines in size of older age groups is a reflection of cumulative, multi-year mortality for the age group.

Recruitment and Broodstock

There was a lack of readily definable year classes over 3+ for most sites. Oysters over 150mm (6 in.) were virtually absent at all sampling sites. Oysters over 110mm (4.3 in.) were rare. Age estimates from length frequencies are less reliable for older oysters. We have not attempted to identify age classes beyond 3+ or occasionally 4+.

Despite variation between sites, individual site population size structures identify the 2+ year class as falling in general between 70-95mm. The 3+ year class was identified as lying between 80-115mm. On a Baywide basis, the 1+ year class was not obvious in 1990, predictably so given the poor 1989 spat set (Krantz 1990). In 1991, the 1+ group was apparent in the 30-60mm range, with a peak at 45mm. Spat set was substantial, although below average, in 1990 (Krantz 1991). We expect that the 1992 survey will show a large peak in the 1+ category because of the large 1991 spatfall (Krantz 1992), unless these oysters are killed by disease in the summer of 1992. Lack of oysters older than 2-3 years within the surveyed population implies that two consecutive years of poor spatfall could substantially reduce Maryland's already depleted oyster populations.

When considering the importance of spatfall and recruitment into the fishery, observations help place the data in perspective. First, it must be understood that spat counts represent counts per volume of substrate dredged, not Bay bottom volumetric or density per unit area determinations. Thus, they may not accurately reflect how dense spatfall is on the bottom itself. Second, spat survival can vary greatly from year to year because of numerous potential sources of mortality. In general however, spat counts on individual oyster bars of ≤ 20 per bushel contribute little toward the fishery in future years; a spatfall of ≥ 300 per bushel is considered a harvestable "set" (a density of 350-450 spat per bushel is considered economical for seed replanting purposes; Krantz 1990). Barring high mortalities, a set of ≥ 300 per bushel will support a productive fishery 2-3 years later.

Spat densities in 1990 were average to poor compared to the historical record, whereas the 1991 set was excellent and extremely high for recent history (Krantz 1991; 1992). Although historical trends in spatfall have been generally downward, high variability between years is typical and is a natural response to environmental conditions in addition to broodstock potential. The high 1991 spatfall may have alleviated some concern that Maryland's oyster broodstock had fallen below a level capable of maintaining the resource. Results from the MFS can shed little light on the question of whether broodstock depletion has affected the reproductive potential of the oyster resource. Full understanding of stock-recruitment relationships in Maryland's oyster populations will require additional research directed toward these questions (Rothschild et al. 1989).

On a Baywide basis, spatfall at the level observed in 1991 should be able to sustain or enlarge the Baywide oyster population and fishery (given their survival to harvestable size). Spat counts, however, do not necessarily reflect fecundity of the breeding population. Oyster larvae which survive to settle as spat probably reflect only a very small proportion of the free-swimming larvae which are produced each year (Kennedy and Breisch 1981). Thus, settlement densities may not be reflective of reproductive activity. Also, after larval settlement, survival rates are highly variable on a yearly basis. Mortality of very small spat can be extremely high (i.e. during the period between settlement and the time when fall sampling occurs; Newell and Kennedy 1991). Therefore, it is possible that the approximately five-fold greater spat counts in 1991 could in fact have been produced by a lesser amount of larval production in 1991 than in 1990. Very favorable environmental conditions for spat survival could also have produced these results.

A further uncertainty in evaluating the implications of the 1991 set for broodstock potential arises from the sampling methodology: only spat densities are measured, not spat abundance. In a condition of limited suitable habitat, larvae will in effect be forced to congregate on what is available rather than disperse in a wider fashion. This available substrate is then accumulated and condensed from wide areas of the bottom by the dredge for the sample. Thus, in the hypothetical situation where available substrate decreases from year to year, the sampling method could inflate spat counts. This is not to say that the apparent high spat-set in 1991 was simply an artifact of sampling methodology, but rather that the results are not useful for estimating the condition of broodstock. It is possible that the dredge samples could be calibrated with the aid of concurrent patent tong samples (for which the area of substrate sampled is known) to provide more useful estimates of spat abundance.

Impact and Implications of Harvest
Although disease has been identified as a major cause of the reduced numbers of marketable oysters, the effects of harvest may also be identified. Figure 26 shows a remarkable similarity in the right hand slope of live oyster size frequency between 80-150mm for 1990 and 1991, despite great differences in the slopes for similar size classes of boxes. In essence, oysters were "disappearing" at almost identical rates with increasing size in both years despite great differences in disease levels. This suggests some additional factor is at play. Figures 56 and 57 show the typical high-peaked composite population structure of harvested oyster bars. Since site variation may obscure year classes, population structure on harvested oyster bars in the Mid-Eastern Shore region will be used as an example of what effect harvest may have on this slope profile.

Harvest bars in this region, and survey-wide, are virtually dependent on the 2+ year class and possibly to some extent the 3+ year class for harvestable oysters. The population profiles for this region in 1990 and 1991 had the near vertical decline of the population slope exactly where marketable size oysters occurred on the horizontal axis (Figure 59). Except for some larger size classes in residual numbers, the slope is smooth, indicative of a well-defined 2+ year class.

Similarity of these slopes may be a direct effect of harvest. For both years, it must be recognized that the MFS was taken after a summer of oyster growth. Thus, peak abundance of the 2+ year class would have been even further to the right immediately after the fall-winter-early spring harvest season. Because disease, as represented by the bulk of observed mortality, was virtually absent, and growth rate in the mid-Eastern Shore region traditionally been considered good, the population appears to be almost totally cropped past harvest size.

In 1991, a 1+ year class in low abundance apparently was entering the population from 1990 spat. Lack of apparent shift to the right of the 2+ year class was not due to inhibition of growth due to disease. Rather, it appears that the effect of harvest cropped the larger individuals in the 2+ year class, which in effect did not allow the age group to appear to increase in size. Presence of a narrower curve in 1991 was due to the increase in size of smaller 1990 oysters found in the size range ~60-65mm in 1990.

The harvest model mortality estimates presented in the results require several assumptions about natural mortality, growth, and recruitment. The assumption of 20mm growth throughout the population for all size classes is arbitrary, yet possibly conservative for the large mode of 1990 oysters centered between 60-100mm. As this size range of oysters comprised the large majority of the model's predicted harvest, and were not of large (i.e. slow-growing) size, the assumed growth rate may not be overestimated. Clearly, better information on growth rates would be helpful in calibrating this or other harvest models.

Selection of the 85mm and larger size classes (as opposed to 76mm or 3 in. harvest size) for calculation of harvest mortality was based on the following criteria. The two size classes eliminated from the analysis (75-79mm and 80-84mm) showed higher actual live oyster counts than predicted oyster counts. With these two data points included in analysis, harvest mortality would be reduced to 31%. Elimination of these data points was done due to the indeterminate effects of seeding in spring-summer 1991 on the left side of the predictive curve. As the population curve of the 1990 live oysters was adjusted to the right to reflect growth, no incorporation of small seed oysters could be made.

Our quantitative knowledge of seed impacts on these oyster bars is poor. However, if the "negative harvest mortality" observed was more than a sampling artifact, the effects of this "artificial" source of recruitment were significant. Because it was unlikely that the seed oysters ever would have recruited to the fishery in their native habitats, due to slow growth and disease pressure, the seed program should be viewed as a source of "real" recruitment. This is an important subject for further analysis.

Comparison of the 1990 and 1991 live oyster population structure in this model prior to "growing" the 1990 population shows the large number of small oysters in the 1991 population which were not present in the 1990 population structure (Figure 63). These seed oysters which entered the 1990 population structure in the 57 and 62mm size classes would have grown out in the model to the 77 and 82mm size classes.

Estimation of 18% as the true annual mortality was based on 1991 average mortality for all size classes between 37 and 122mm. Larger and smaller size classes were excluded due to low counts of live oysters and boxes, resulting in large apparent mortality fluctuations. Although mortality within the selected size ranges varied between 27% and 11%, no pattern based on size class was noted. The low estimate of predicted natural mortality compared to observed mortality (Figure 63) was not problematic because actual mortality of the 1991 population was used in the model. Size classes where observed mortality was higher than predicted (67-87mm) were size classes where 1991 mortality was higher than the average.

Although Maryland oyster populations may appear to be at near remnant levels, the oyster in Maryland should in no way be considered endangered. The crisis is one of the oyster industry and to some extent a way of life. Oysters are present in large numbers in Chesapeake Bay. Their density on oyster bars has however been reduced to a level where harvest is not economically feasible on the majority of the Bay's oyster bottom. A small number of oyster bars largely within the Upper Bay and Chester River, which disease has not heavily impacted, and which to a large extent are supplemented by seed planting, currently support the entire Maryland fishery.

Potential for Management

The current scenario has been caused by a combination of three factors: disease, habitat loss, and harvest. Although the individual contribution of each of these three factors cannot be determined quantitatively by the MFS at present, together they have created the current situation (Newell and Barber 1991).

In the case of disease, little can be done in the short term to mitigate the situation. Proper transplantation of seed can lessen to some extent the overall impact of *P. marinus* disease. No "cures" are available, or foreseen, to lessen the effects of disease. Development of natural or genetically selected resistance in oysters to these diseases continues to be investigated, but again holds no short-term promise.

No one can predict how the diseases *P. marinus* and *H. nelsoni* will behave in the future. Examination of historical Maryland data shows that both diseases have fluctuated in their range and intensity in Maryland's Chesapeake Bay from the 1950's onward. The recent series of warm winters and dry summers has contributed to the historically high level of *P. marinus* disease. Certainly if conditions become unfavorable for parasite survival again, their impact will lessen. In the short term, *P. marinus* disease will likely remain at high and lethal levels within the oyster population. In addition, *H. nelsoni* appears resurgent in Chesapeake oyster populations. Largely undetected in Maryland's Bay in recent years (Cooperative Oxford Laboratory records), *H. nelsoni* is returning apparently because of high salinities favorable for its increase and spread.

Habitat loss is a chronic rather than a short-term phenomenon, largely attributed to sedimentation and burial of shell which spat require for setting (USEPA 1983). Over the long term, removal of oysters (i.e. shell) from oyster bars and physical disturbance associated with harvests may have contributed to habitat loss (USEPA 1983). The role of harvest on the condition of oyster habitat is difficult to determine, although detrimental effects on oyster populations and habitat were reported as long as 100 years ago (Stevenson 1894). Replenishment of oyster bottom by the placement of dredged fossil shell has been successful in rejuvenating some areas of the Bay bottom (Abbe 1988).

A curious note concerning habitat condition is the effect of disease-induced mortality on oyster bars. Oysters dying of disease are not going to be removed from the bottom by harvest. Thus, in a sense, they are a natural replenishment to oyster bars. This contribution should not be ignored in terms of its overall contribution to habitat enhancement. Our results clearly show the large percentage of boxes being added to the substrate. In some regions of the Bay where mortality is highest and adult oysters not abundant enough for harvest, dredge samples come aboard filled with freshly dead shell. This fresh cultch is available for spat settlement.

The Modified Fall Oyster Survey—Design Considerations and Evaluation

Survey Design Criteria

SITE SELECTION

Although the number of sites selected for the MFS was to a large extent dictated by logistics, the results presented in this report indicate that 64 sites is an adequate number to characterize the condition of Maryland oyster populations (there are over 1000 recognized "oyster bars" in Maryland, however, many of these currently exist in name only). Variations in oyster mortality, spatfall, and size frequency between 1990 and 1991 appeared to be attributable to changes within the populations and not sampling variability.

Site selection was not optimal with respect to the regional aggregations presently employed to represent geographic and fishery zones. The zones contained different numbers of sites, complicating quantitative regional comparisons. The mapped zones used for this work were generic regions created prior to site standardization in the MFS. We are exploring alternative schemes for regional aggregation of the data.

Subsetting the survey sites for disease diagnosis (43 of 64 sites or 69%) caused some difficulty in comparative analysis with the overall MFS bars. The number of disease sites chosen was based primarily on laboratory processing constraints. Laboratory diagnosis of all MFS sites would be helpful in the future if staff and budgets would permit it.

The validity of consistently sampling the same oyster bars every year can be questioned in light of the fluidity of oyster survival on individual bars. For several of the sampling sites, the number of live animals was less than is generally considered characteristic of viable oyster bars. Natural dynamics, in addition to disease and harvest, are likely to result in long-term changes in the locations of productive bars. However, historical consistency, and long-term trend information are important objectives of the MFS, and sites should not be replaced simply because they are relatively unproductive. A valid reason for deleting a survey site would be the virtual absence of shell, indicating that it is no longer oyster habitat. A valid reason for adding sites would be if new, unsampled, areas of bottom were to produce significant harvests or amounts of seed oysters.

Sampling Regime

The fall (October-November) time frame for the annual survey was dictated by two factors: 1) spat which set in summer reach a size at which they can be identified by the unaided eye and are past the early period of extremely high mortality; and 2) most of the adult mortality associated with *H. nelsoni* and *P. marinus* occurs during the summer. One drawback of this sampling period is that the oyster fishery season begins in October. Thus, on some oyster bars, an unknown portion of the adult population will be removed just before and during the MFS. If an objective of the survey were to assess the effects of harvest, an earlier survey would be better, however, a September survey would cause problems with mortality and spatfall estimates.

Incorporation of a spring sampling period in addition to the fall period has been recommended (Newell and Barber 1991), primarily for the purposes of estimating spat survival prior to the second year of growth and winter mortality. A late spring or early summer survey could also provide estimates of disease mortality before the start of the harvest season. Initiation of additional surveys has been precluded by a lack of resources to gather and process samples.

Gear considerations

A bottom dredge is used for oyster bar sampling in the MFS. Recent oyster stock assessment work has employed patent tongs as the primary gear. Each gear type has merits and disadvantages which depend upon the objectives of the sampling program.

Patent tongs remove a relatively constant volume of the bottom, thus allowing for sample size quantification. The bottom dredge removes upper surface substrate over an unquantifiable swath of the bottom. Patent tongs undoubtedly are superior to dredges for statistical quantification of results when data are required for a discrete, homogeneous area of oyster bottom (Rothschild et al. 1989). Material in the tongs can provide absolute abundance estimates for a given area or volume of the bottom. Therefore, tong sampling can provide population estimates with confidence intervals (e.g., total number of oysters on a given oyster bar, or average number of oysters km^{-2} in a given river system).

Because the dredge integrates a relatively large area of bottom, it provides repeatable estimates of various population characteristics with minimum effort. Adaquate coverage of 64 oyster bars by patent tongs would require great increases in labor and logistics over what is currently employed. The inability to estimate absolute oyster abundance with dredge results is a serious drawback for making reliable estimates on individual oyster bars, but is a less serious problem and a necessary trade-off when evaluating the regional condition of the stocks and long-term trends. Inclusion of a patent tong analysis in conjunction with the MFS would be advantageous. Dredge data could then be calibrated to units per area.

Sample Size

The original decision to take five dredge replicates of 0.2 bushels each (1.0 bushel total at each site) was based on the following considerations. Cursory examination of historical Fall Survey data (0.5 bushels of shell analyzed from a single trawl at each site) indicated that size class structure on oyster bars having low to moderate oyster densities was not readily apparent from a 0.5 bushel sample. Because prior Fall Survey data was multiplied by 2 prior to entry on field data sheets to represent 1.0 bushel of material, the 1.0 bushel total sample in the MFS is consistent with historical data.

Replicate sampling was initiated for two major purposes: 1) to provide for more diversified sample area coverage than a single trawl; and 2) to allow statistical inferences to be made on the portion of the oyster bar population where the sample was obtained. Results from one sample can provide only information about the sample itself; replicate sampling allows inferences to be made about the population on the oyster bar.

The overall sample size and the number of replicates comprising the sample were a compromise between statistical confidence and practicality. Also, unlike studies where sampling is conducted for a single variable and sample number can be optimized for a specified confidence limit, many variables are sampled in this survey. On an individual site basis sample size and replicate number were chosen to adequately represent, in order of importance, the following population parameters:

- Age structure and relative population size
- Mortality by size class
- Disease pressure
- Relative spatfall (spat density)
- Recruitment of spat into the population and fishery

The results for three sampling sites indicate that interpretation of age class and population size is adequately served by the existing sample size (see Figures 36, 37, and 38). Mortality as a component of age group also appears to be well-defined by the existing sample size. A weekly survey conducted on the Choptank River in the summers of 1986-1988 indicated that trawl samples gave highly reproducible estimates of mortality when repeated over relatively short time intervals (Christmas and Jordan 1991).

The sample size for disease analysis (a single sample of 30 oysters from each site) was based on an existing Cooperative Oxford Laboratory protocol. According to binomial probabilities, if no disease is observed in a 30 oyster sample, the upper 95% confidence limit on the prevalence of disease in the sampled population is 11.6% (Sokal and Rohlf 1973).

The value of replicate sampling for spat counts was demonstrated for three randomly selected sites (see Figure 14). Results clearly showed the value of increasing the number of 0.2 bushel samples. The 95% confidence limits evaluated are overly stringent for spat counts (e.g., 90% would be more reasonable); however, the pattern of increased resolution would be similar for lower confidence levels. With less than 4-5 replicates, confidence limits for spat counts were unacceptably broad.

A statistical assumption of some significance to the accuracy of these results is that spatfall must be randomly distributed on substrate for the confidence limits to be valid. Because we have not yet tested this assumption, the confidence limits should be viewed more as general indicators of possible sample error than as exact estimators.

One site (MRAS) showed a narrower confidence interval with decreasing numbers of replicates. This was because the removal of replicates at random by chance removed the higher spat counts. The remaining samples, therefore, had a lower range and mean than the full sample. Confidence limits on very low mean spat counts are of little concern, because they predict virtually zero potential recruitment.

Translation of yearly spat counts into future harvest potential is a basis for any predictive model. As with most marine invertebrates, the number of surviving young compared to number of larvae produced is incredibly small (Galtsoff 1964). However important this factor is to ultimate oyster fishery recruitment, its magnitude is unmeasurable; and no management action can mitigate its effect. However, once a spat has obtained a reasonable size (i.e. at the time of the Fall Survey), the chance of survival throughout the first year should be reasonably high, given the absence of adverse environmental factors such as disease. A determination of expected spat survival into the 1+ year class (i.e. from one Fall Survey to the next) would provide background into potential recruitment and also might support an analysis of how environmental conditions affect recruitment.

Our results (Table 4; Figure 15) suggest that sample size or method of analysis is not adequate to determine incorporation of spat into the 1+ year class with any level of confidence. Additional analysis and survey modifications (e.g., spat measurements) may shed more light on this question.

Improvements to Sampling Methodology

EFFECTS OF REPLETION (SEED AND SHELL)

Seeding and shelling of survey oyster bars complicates interpretation of MFS results.

Because placement of these materials is not uniform over the bottom, judgement based on visual examination of each sample is necessary to assess whether such material is present. The dates, locations, and areas within oyster bars of seed and shell placement need to be included in the MFS database.

Oyster bars within Maryland's Chesapeake Bay may generally be considered as two types from a management perspective: those which are replenished with seed or shell, and those which are not. To the extent that the purpose of the survey is to assess natural populations of oysters, it would be beneficial if the MFS portion of oyster bars sampled were not subjected to seeding or shelling as a matter of policy. Although similar sampling methods could be applied to modified oyster bars for the purposes of assessing success of plantings, MFS bars could be reserved for assessing the natural background conditions of the populations. From another perspective, however, seed and shell transplants are "real world" components of oyster stocks. They may compromise estimates of "natural" mortality and recruitment, but we are left with a semantic question of what is natural.

SPAT MEASUREMENT

Currently, spat are not sized due to time constraints. As oyster spawning may occur throughout the spring and summer, great differences in spat size are observable during the MFS. Variations in growth rates and the timing of spatfall may be great on all scales from Baywide to individual animals on a single oyster bar.

Variable size of spat at the end of their first summer after settlement may be responsible in part for the difficulty in identifying the contribution to the 1+ year class the following year. Inclusion of spat measurements would be advantageous to the MFS. As spat counts can be very large at some locations and times, a measurement of perhaps the first 50 spat encountered might suffice to generate a reasonable size frequency curve. Note that because of the lack of spat measurements and the somewhat arbitrary nature of the distinction between "spat" and "smalls", the area of the size frequency diagrams (e.g., Figure 36) below about 40mm is essentially meaningless.

In the historical Fall Survey, spat box counts were made as an estimation of spat mortality. This was not included in the current MFS. Disintegration of spat boxes is so rapid that accurate estimates of mortality cannot be obtained from an annual survey.

PHYSICAL DATA

Currently surface salinity, temperature, and depth are the only physical or water quality data collected by the MFS. Although salinity is correlated with the spread and extent of both *P. marinus* and *H. nelsoni* (Andrews 1988), salinity at the time of sampling has little correlation with *P. marinus* disease levels (see Figure 48). Although the overall salinity regime during the previous summer surely would show stronger correlation, these data are not available on a site-specific basis. Baywide spatial interpolations of salinity and temperature data on a seasonally averaged basis from the Chesapeake Bay Monitoring Program could generate more useful estimates of these variables for the MFS sites.

DISEASE SUBSAMPLE

Currently the disease sample is selected from the pool of oysters accumulated from the five dredge tows. It has been suggested that disease samples be selected from replicate trawls. That is, six oysters could be chosen at random from each of the trawls to produce the sample of 30. This procedure would allow for better estimates of variation and confidence for disease variables, however, the logistic burden, especially for the laboratory, would be significant.

Oysters collected for pathology were of larger mean size than the populations from which they were obtained in both 1990 and 1991. Disease sample oysters were, on the average, market size; while survey oysters as a whole averaged at about the break point between smalls and markets. If the disease subsample is to be representative of the population as a whole, selection should be random. In general, the effect of selecting larger oysters for disease analysis should be to bias the results toward higher disease prevalence and intensity. For the 1992 MFS, oysters will be selected at random from the pool of dredged oysters.

Box Classification

Dead oysters are classified in the MFS as gaper, class 1, class 2, and class 3 in order of increasing apparent time since death. This classification is consistent with historical survey data. As the large majority of box classifications are class 3, short-term mortality is generally a small portion of overall mortality. In areas with high disease mortality rates, samples taken during the summer months often show higher rates of recent mortality than Fall Survey samples (SJJ; personal observation). Indication of high recent mortality is of interest on an individual oyster bar basis but not of high overall importance in terms of yearly monitoring. Since box classification entails little extra effort, it is recommended that the procedure be retained in the MFS.

Management and Analysis of Survey Data

Extensive monitoring programs produce large amounts of data and can generate large amounts of information, some useful, some not. Although many graphics and tables are contained in this report, they represent only a small portion of the data and statistics generated by the MFS. One purpose of this report is to solicit suggestions as to what data and analysis scientists and management personnel would like to see presented and summarized on an annual basis.

A successful oyster monitoring program should be able to provide information on three aspects of management:

- Biological and ecological conditions and trends of the resource;
- Determine where regional oyster enhancement strategies should be undertaken and monitor their progress;
- Assess the relative impact of harvest on the resource.

Information provided in this report addresses only the the first of these issues. Incorporation of refinements discussed below should improve the program's ability to address the last two issues.

Data Development and Presentation Format

Primary statistics currently generated (Appendix A) fall into nine general categories of information types. On a bar by bar basis these are:

- Numbers of live oysters and boxes expressed as "smalls" or "markets"

- Mortality categorized as to recent or long term for "small" and "market" size groups
- Size information for small and market oysters
- Spat densities
- Type and amount of fouling organisms
- Impacts due to seeding and shelling
- Disease indices for *P. marinus* and *H. nelsoni*
- Oyster condition and other parasites
- Population profiles comprising oyster size and comparative abundance information

Except for the last category, all components of the MFS data are traditional statistics which express the condition of Maryland's oyster populations. All categories of information except fouling and seeding and shelling information have been synthesized to produce results for this report. Incorporation of disease data directly into survey computer files is a new component of the monitoring system. This modification has indicated the need for consistency in laboratory analysis methods. Currently multiple techniques may be used for the analysis of *P. marinus* and *H. nelsoni*. Standardization is important for long-term monitoring. In the case of *P. marinus* disease, results presented for both years were generated by rectal thioglycollate culture technique. Although this has been the historical analysis method, its use has been partially replaced by a blood thioglycollate procedure.

Although similarity of the diagnostics has been shown in the results, it is recommended that blood analysis should be the standard technique for the MFS. The technique is quantitative in terms of clinical staging and most likely to be more representative of disease within an individual oyster than the rectal assay. Positive identification of disease occurs only when the infection is systemic, whereas the rectal method detects disease agents in the digestive tract. Although the rectal technique may be more sensitive to parasite detection, staging may not be representative of true infection as opposed to ingestion of infectious agents.

Although the results of the two techniques for the MFS were similar, this may not be the case during other seasons. In spring when new infections occur, the rectal technique may detect initial infections prior to their entering the blood. This effect is reduced during the MFS when summer-long infections have had a chance to enter the blood.

Analysis for *H. nelsoni* similarly has multiple techniques. Results presented for 1990 and 1991 used mixed techniques. As with *P. marinus*, a standardized analysis (blood histocytology) will replace tissue examination for the presence of this disease in future surveys.

SIZE-FREQUENCY ANALYSIS

The incorporation of individual oyster measurements in the MFS showed the distinct population age structures unique to individual oyster bars. In effect, age classes on individual bars respond in different ways, and translate the impacts of factors of previous years to year class size, growth, disease, and mortality. Representing data as an average for all year classes within a site or region produces a useful composite average but does not effectively describe the natural situation.

Although there were clear modal size groups at many sites, interpretation of the modes as specific age classes was not straightforward or certain. It is possible that when spat measurements are added to the MFS, we will be able to track age classes from year to year on a given bar, because it will be certain that the first mode will be age 0+, except in the absence of spatfall.

SURVEY CALIBRATION NEEDS

Lack of area or volumetric quantification of the dredge samples, possible biases in mortality estimates, and the volume of fouling organisms (especially tunicates, *Molgula manhattensis*) introduce potentially important sources of error into MFS results.

No absolute density or abundance information can be derived from the current survey. Patent tongs could be used to develop calibration coefficients for the dredge samples by estimating the amount of substrate (shell) per unit area of oyster bar. By knowing bushels of shell m^{-2} (patent tongs), numbers of oysters (spat, markets, etc.) per bushel (dredge samples), and the area of the bar (maps, patent tong surveys), absolute abundance estimates could be made from the dredge survey. Whether these estimates could be generated with a reasonable amount of effort or would have enough precision to be useful cannot be determined until the method is tried.

The traditional assumption is that the time frame of mortality estimates is one year. That is, all of the boxes (dead oysters with the valves still attached) counted during the MFS are assumed to have died within the year since the previous survey. Spatial and temporal factors such as salinity and temperature could affect the hinge disintegration process and cause variability in disarticulation time. Studies are currently underway to assess variation in disarticulation based on oyster size and location. This information will be used to calibrate mortality estimates and to test the validity of the annual mortality assumption.

At some sites fouling may be extremely heavy during a given year. Although the sampling protocol includes removal of fouling organisms prior to selecting subsamples, in many cases this cannot be done completely. The percentage of fouling in a sample could be used to adjust substrate volumes so that all samples would be based upon equivalent volumes.

Recommendations for Future Improvements to the Survey and for Uses of Data

INTERACTIVE STATISTICS

Oyster population variables have been presented in univariate mode for the purposes of this characterization report. For example, mortality is presented in one figure and disease levels in another. The following components of oyster populations are linked in many ways: spatfall, recruitment to adult populations, size and growth of year classes, disease, mortality, and harvest. Site or regional classifications that take all or some of these important variables into account could be very useful to management. Multivariate classification techniques (e.g., discriminant analysis) can be employed for this purpose. The classifications would be objective, yet could be tuned to reflect management interests as well as biological characteristics.

For example, a region which was unsuitable for the transplantation of seed might exhibit moderate to high spatfall, two well-defined year class groups, near 50% mortality in the 2+ age group, beginnings of mortality in the 1+ year class, and high disease indices. A contrasting classification might be bars that have low spatfall, low disease indices, and a substantial population of older year classes.

Potential for Population Modeling

Additional types of data need to be incorporated before the MFS data can be used for population modeling: harvest information, physical data, and historical data.

Harvest data are not available on a bar by bar basis. Regional records of landings are maintained, but these largely reflect the point of landing and not necessarily the region of harvest. Although oyster bars on which harvest activity was observed were segregated for purposes of analysis, the effect of harvest on population structure cannot be properly quantified. Short of monitoring harvest on MFS bars, there is no adequate way to determine the impact of harvest on MFS bars. A second sampling of harvested oyster bars after the harvest season (spring) might provide some information on what was removed after fall sampling. This activity would require considerably less effort than the Fall Survey, because only a fraction of MFS bars are harvested each season.

Without information to determine what component of the population has been removed by harvest, an integral and necessary component of any model would be lacking. At a minimum, we should have reliable information on which of the sampled bars has been harvested each year.

Repletion data were included in the data base in order to examine the effects of seed and shell on the oyster population. However, because the data were found to be inconsistent and in need of verification, they were not analyzed for this report. Because repletion can have great effects on population comparisons, seed and shell variables must be included in the data. One method for using this information is to assign a vector for each oyster bar, with the X and Y coordinates representing the cumulative weights of recent (5 year) seeding and shelling activity. Given accurate data, this system could be used to evaluate the effectiveness of repletion as well as its effects on population structure.

Historical Population and Disease Data

Historical Fall Survey data can be verified back to approximately 1980 and are available for inclusion within the MFS data base. Oyster disease data are present from 1963 onward and currently available on disk. The major difficulty in incorporating these data sets with MFS data is the lack of site consistency. Sampling sites were highly variable in number and location from year to year. Interpolation techniques where data for unsampled areas can be generated from areas which were sampled may hold some promise for improving this situation.

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VII. APPENDICES

Appendix A. Modified Fall Survey Data Storage Files and Field Descriptions

Disease and population data from the Modified Fall Survey are entered into dBase III+ files at the Cooperative Oxford Laboratory. Summary documentation for the data management system is presented below. Data are stored in three main files:

- ARRAY.DBF—individual oyster records of mortality and shell length based on 0.2 bushel subsamples
- ARRAYA.DBF—spat counts by subsample, salinity and temperature for each sample, fouling data, and bar repletion history;
- ARRAYB.DBF—disease and detailed population data for each sample.

Field descriptions—ARRAY.DBF

SITE: four letter oyster bar identifier. First two letters represent Bay region, last two letters oyster bar name (see Table 1).

DATE: date of field sampling, dBase American date format (mm/dd/yy).

SMPNUM: subsample number 1 to 5.

CLASS: size frequency class by 5mm groups. Represented in file by midpoint value of class (45-49mm listed as 47).

BOXTYP: dead oysters G=gaper, 1=class 1, 2=class 2, 3=class 3. Field left blank for live oysters.

Field Descriptions—ARRAYA.DBF

SITE: as in ARRAY.DBF

DATE: as in ARRAY.DBF

SAL: salinity (ppt), water surface.

TEMP: temperature (°C), water surface.

DEPTH: as recorded on fathometer (feet).

SURTYPE: survey type, currently Fall Survey (F) or Other Survey (O).

BARTYPE: currently Natural (N), Seed (S), Other (O).

SPAT1: spat count subsample # 1.

SPAT2: spat count subsample # 2.

SPAT3: spat count subsample # 3.

SPAT4: spat count subsample # 4.

SPAT5: spat count subsample # 5.

MUS: mussel (generally *Brachidontes recurvum*) fouling of sample (%), designated live or dead, currently percent of trawl sample volume due to fouling (prior to removal of subsamples). Fouling is removed from subsample material prior to volumetric determination.

MOG: tunicate (*Molgula manhattensis*) fouling (%), determined as above.

OTH: % other fouling (type noted - typically barnacles), determined as above.

TOTPER: total percent fouling of trawl sample (sum of MUS, MOG, and OTH).

SEED: seeding impact to sampled portion of oyster bar; field length six characters; leftmost character is seeding conducted in present year; each character to right indicates seeding one year prior to current year (i.e. character space 5 is seeding four years previous). Character space 6 is seeding any time prior to 4 years previous. Presence of "X" in space(s) denotes seeding; "Y" in space(s) denotes visual confirmation of seed in dredge sample; example— "Y XX " (1991 sampling)=1991 seed observed in sample, bar seeded 1988, not visually noted, bar seeded 1987, not visually noted.

SHELL: shelling impact to sampled portion of oyster bar, both fresh and fossil shell; data representation as with "SEED".

Field Descriptions—ARRAYB.DBF

SITE: as in ARRAY.DBF

DATE: as in ARRAY.DBF

YEAR: two number character designator for year (i.e. "91").

SAL: as in ARRAYA.DBF

TEMP: as in ARRAYA.DBF

DEPTH: as in ARRAYA.DBF

SURTYPE: as in ARRAYA.DBF

BARTYPE: as in ARRAYA.DBF

TOTLIV: total number of live oysters from five subsamples (1.0 bu.).

TOTBOX: total boxes (dead oysters), all stages, combined for five subsamples (1.0 bu.).

TOTMRK: total number of "market" oysters ≥3 in. (75mm) in total combined samples.

TOTSML: total number of "small" oysters (<3 in.), excluding spat, measured if greater than 15mm.

SMLMRKRAT: small to market ratio. (TOTSML/TOTMRK).

MRKBOX: market box count, total number of market boxes, all stages.

SMLBOX: small box count, total number of small boxes, all stages.

STMRKBOX: short-term market box count, box stages "gaper", "stage 1", "stage 2", included.

STSMLBOX: short-term small box count, as with short-term market box count.

LTTOTMRT: long-term total mortality, mortality of combined small and market oysters, all stages (TOTBOX / (TOTLIV + TOTBOX)) * 100.

LTMRKMRT: long-term market mortality, as with long-term total mortality, but market oysters only.

LTSMLMRT: long-term small mortality, as with long-term total mortality but small oysters only.

STTOTMRT: short-term total mortality, as with long-term total mortality but gaper, stage 1, and stage 2 boxes only.

STMRKMRT: short-term market mortality, as with long-term market mortality but gaper, stage 1, and stage 2 boxes only.

STSMLMRT: short-term small mortality, as with long-term small mortality but gaper, stage 1, and stage 2 boxes only.

AVGTOTSIZ: average total size, average size (mm) of market and small oysters combined.

AVGMRKSIZ: average market size, average size (mm) market oysters only.

AVGSMLSIZ: average small size, average size (mm) small oysters only.

AVGSTBOX: average short-term (gaper, stage 1, stage 2) box size (mm), markets and smalls combined.

AVGLTBOX: average long-term (all stages) box size (mm), markets and smalls combined.

SPTBUS: spat per bushel, combined total of 5 0.2 bu. subsamples.

MUS: as in ARRAYA.DBF

MOG: as in ARRAYA.DBF

OTH: as in ARRAYA.DBF

TOTPER: as in ARRAYA.DBF

XSEED: impact of seeding described as distance on X-axis coordinate, magnitude based on decreasing impact from current year. (i.e. seeding in current year = 16, one year previous = 8, two years previous = 4, three years previous = 2, four years previous = 1, prior to four years = 0.5); magnitude of impact is sum of values in which seeding occurred; values assigned from character placements in file ARRAYA.DBF, field SEED; e.g., "X X X" (1991 sampling), 1991 seed = 16, 1988 seed = 2, historical seeding = 0.5, total seed magnitude = 18.5.

YSHELL: impact of shelling described as distance on Y-axis coordinate, determination as with XSEED above.

IMPMAG: seed and shell combined impact; vector of X-Y coordinates reflecting combined impact of seeding and shelling $[(XSEED^2 + YSHELL^2)^{-2}]$.

SMPSIZ: disease sample size, typically 30 oysters.

AVGSIZ: average oyster size in disease sample (mm).

MAXSIZ: maximum oyster size in disease sample.

MINSIZ: minimum oyster size in disease sample.

AVGCOND: average oyster meat condition, total disease sample; individual oysters scaled 1-9 (watery-, watery, watery+, medium-, medium, medium+, fat-, fat, fat+).

MAXCOND: highest oyster meat condition in sample.

MINCOND: lowest oyster meat condition in sample.

DBLDPREV: *P. marinus* blood prevalence (%); percent of oysters in sample having detectable *P. marinus* by blood analysis (hemolymph cultured in thioglycollate medium).

DTALPREV: *P. marinus* rectal prevalence (%); percent of oysters in sample having detectable *P. marinus* by rectal culture in thioglycollate medium.

DBLDINT: *P. marinus* blood intensity index; staging of parasitic infection in individual oysters, scored on a scale of 0 (not detectable) to 7 (highest stage); the index is defined in the text of this report.

DTALINT: *P. marinus* rectal intensity index; staging and index as with DBLDINT.

DBLDSIZ: *P. marinus* blood severity index (see text).

DTALSIZ: *P. marinus* rectal severity index.

MBLDPREV: *H. nelsoni* blood prevalence (%); percent of oysters in sample having detectable *H. nelsoni* by blood analysis (histocytology rapid diagnosis).

MTISPREV: *H. nelsoni* tissue prevalence (%); percent of oysters in sample having detectable *H. nelsoni* by microscopic tissue examination (histopathology).

MBLDINT: *H. nelsoni* blood intensity index (see text).

MTISINT: *H. nelsoni* tissue intensity index (see text).

MBLDSIZ: *H. nelsoni* blood severity index (see text).

MTISSIZ: *H. nelsoni* tissue severity index (see text).

CLIO: *Cliona* sp.: boring sponge which can weaken oyster shell and allow secondary invaders into the oyster (% of sample infected).

POLY: *Polydora websteri*—a tube-dwelling worm found inside of the shell of oysters; with severe infestation it may stress oysters (% of sample infected).

PROKA: prokaryotes, commonly *Rickettsia* and *Chlamydia*, associated with cell destruction in shellfish species (% of sample infected).

PAPA: *Papova* virus—located in and causes destruction of oyster gametes (% of sample infected).

ANCIS: *Ancistrocoma pelseneeri*, ciliated thigmotrichs found in the digestive system—indicators of stress (% of sample infected).

THIG: ciliated thigmotrichs found attached to oyster gills; in large numbers they may interfere with respiration and or cause mechanical damage or stress (% of sample infected).

BUC: *Bucephalus cuculus*, a digenetic trematode which infects and destroys oyster gonad tissue, causing sterility (% of sample infected).

XCOORD: sampling site latitude on the oyster bar expressed in decimal degrees, used for geocoding of data for graphic representation and analysis.

YCOORD: sample site longitude in decimal degrees.

Data Field Conventions
-9 represents a missing numeric field.

-8 represents data not available at present, typically used for disease data not yet processed.

Appendix B. Spat Counts by Subsample (0.2 bushel of dredged material) and Total per Site (1.0 bushel)

SITE	DATE	1	2	3	4	5	TOTAL
BCDN	10/18/90	15	10	9	9	5	48
BCDN	10/22/91	96	102	129	68	73	468
BNMP	10/28/90	0	0	0	0	0	0
BNMP	10/28/91	0	0	0	0	0	0
BNSP	10/23/90	0	0	0	0	0	0
BNSP	10/27/91	0	0	0	0	1	1
CHBR	10/22/90	0	0	0	1	0	1
CHBR	10/25/91	0	0	0	0	0	0
CHOF	10/22/90	0	0	0	0	0	0
CHOF	10/25/91	0	0	0	0	1	1
CRCP	10/16/90	6	2	1	6	2	17
CRCP	10/21/91	43	24	30	31	39	167
CRLI	10/17/90	5	4	10	5	3	27
CRLI	10/21/91	77	103	95	100	85	460
CROS	10/17/90	2	1	0	0	1	4
CROS	10/18/91	22	8	6	19	12	67
CRRO	10/18/90	9	10	13	14	11	57
CRRO	10/22/91	145	110	112	110	118	595
CRSH	10/17/90	8	4	9	7	10	38
CRSH	10/18/91	37	26	38	43	35	179
CRTW	10/16/90	11	28	27	15	20	101
CRTW	10/21/91	138	173	89	152	167	719
EBBU	10/22/90	6	4	0	0	1	11
EBBU	10/24/91	24	17	21	12	4	78

SITE	DATE	1	2	3	4	5	TOTAL
EBHN	10/24/90	0	1	1	0	0	2
EBHN	10/23/91	1	3	3	2	2	11
EBPI	10/19/90	2	2	1	0	2	7
EBPI	10/24/91	5	30	26	30	36	127
EBWG	10/19/90	2	2	4	4	6	18
EBWG	10/23/91	55	38	35	37	40	205
FBCI	11/05/90	3	4	5	3	4	19
FBCI	11/12/91	51	55	38	54	67	265
FBGC	10/08/90	2	1	1	0	1	5
FBGC	11/12/91	24	31	43	26	29	153
HCEP	10/18/90	0	6	2	5	6	19
HCEP	10/22/91	70	102	70	79	66	387
HOHO	10/08/90	19	28	35	51	35	168
HOHO	11/13/91	99	51	38	43	38	269
HRNO	10/08/90	7	9	15	4	10	45
HRNO	11/13/91	211	240	233	219	256	1159
HRWI	11/09/90	38	23	20	35	36	152
HRWI	11/13/91	148	176	166	132	118	740
LCCA	10/15/90	33	22	28	29	31	143
LCCA	10/16/91	523	182	382	505	247	1839
LCRP	10/18/90	6	13	19	13	14	65
LCRP	10/15/91	232	192	176	229	207	1036
MADP	11/14/91	27	35	26	28	24	140
MAGE	10/09/90	11	0	1	1	1	14
MAGE	11/14/91	7	13	10	12	10	52
MESR	10/16/90	4	7	8	4	14	37
MESR	10/21/91	58	70	70	81	76	355
MRAS	10/18/90	0	0	1	0	1	2
MRAS	10/24/91	4	1	7	0	0	12
MRBI	10/22/90	0	1	0	1	0	2
MRBI	10/24/91	2	4	4	1	1	12
MRLP	10/18/90	0	0	0	0	0	0
MRLP	10/24/91	1	0	2	1	0	4
MRTU	10/22/90	1	4	1	5	0	11
MRTU	10/24/91	32	44	30	33	29	168
NRMG	10/08/90	9	7	8	6	10	40

SITE	DATE	1	2	3	4	5	TOTAL
NRMG	11/12/91	26	25	28	15	13	107
NRWE	10/08/90	0	1	1	0	1	3
NRWE	11/12/91	0	0	1	2	0	3
NRWS	10/08/90	1	3	2	4	2	12
NRWS	11/12/91	0	1	3	2	3	9
POSH	10/18/90	7	12	15	9	5	48
POSH	10/23/91	15	12	13	13	26	79
PRBS	10/30/90	0	0	0	1	0	1
PRBS	11/06/91	6	3	6	5	2	22
PRBW	10/30/90	1	0	0	0	0	1
PRBW	11/06/91	0	1	2	2	1	6
PRCH	11/01/90	6	10	5	10	5	36
PRCH	11/04/91	66	34	48	27	37	212
PRLC	10/30/90	0	0	0	0	0	0
PRLC	11/05/91	11	13	11	14	10	59
PRDC	10/30/90	0	0	1	0	0	1
PRDC	11/06/91	1	5	5	5	3	19
PRRP	10/30/90	0	1	0	1	0	2
PRRP	11/06/91	4	9	4	6	3	26
PSGU	11/15/90	6	4	4	5	2	21
PSGU	11/18/91	57	70	53	56	66	302
PSMA	10/09/90	0	0	0	1	0	1
PSMA	11/18/91	27	23	27	34	31	142
PXBA	11/02/90	2	1	3	5	3	14
PXBA	11/08/91	9	10	13	4	13	49
PXBI	11/02/90	2	0	1	0	0	3
PXBI	11/08/91	0	2	2	2	2	8
SMCC	10/29/90	5	4	6	9	5	29
SMCC	11/04/91	40	26	34	35	47	182
SMPA	10/29/90	96	118	172	85	142	613
SMPA	11/04/91	10	13	4	3	6	36
TADM	10/17/90	1	0	0	0	0	1
TADM	10/22/91	27	17	30	29	26	129
TSBC	10/08/90	29	36	34	31	29	159
TSBC	11/14/91	76	75	71	60	63	345
TSGR	11/16/90	16	16	9	16	9	66
TSGR	11/18/91	50	42	28	68	20	208

SITE	DATE	1	2	3	4	5	TOTAL
TSOW	10/09/90	48	76	36	49	48	257
TSOW	11/18/91	33	15	10	15	21	94
TSPI	10/09/90	26	17	18	26	21	108
TSPI	11/14/91	96	81	77	80	95	429
TSSS	10/08/90	6	3	3	5	8	25
TSSS	11/12/91	10	8	6	8	11	43
TSTE	11/14/90	49	43	30	38	44	204
TSTE	11/14/91	65	42	52	65	65	289
UBBH	10/24/90	1	0	1	0	1	3
UBBH	10/28/91	0	0	0	0	0	0
UBHA	10/24/90	0	0	0	0	0	0
UBHA	10/27/91	0	0	0	0	0	0
UBTS	10/24/90	0	0	0	0	0	0
UBTS	10/29/91	0	0	0	0	0	0
WRES	11/05/90	1	1	2	7	2	13
WRES	11/12/91	6	4	2	5	3	20
WRMV	11/06/90	0	0	0	0	0	0
WRMV	11/12/91	0	5	3	7	0	15
WSBU	11/01/90	14	12	11	10	6	53
WSBU	11/07/91	131	141	103	110	132	617
WSFP	11/01/90	0	1	1	2	0	4
WSFP	10/30/91	60	49	72	71	78	330
WSHI	11/01/90	0	1	1	2	3	7
WSHI	11/07/91	39	17	41	34	38	169
WSHP	10/24/90	0	0	0	0	0	0
WSHP	10/30/91	0	0	0	0	0	0
WWLA	10/31/90	0	0	0	0	0	0
WWLA	11/05/91	5	3	10	12	9	39
WWMW	10/31/90	0	1	1	0	0	2
WWMW	11/05/91	12	17	15	15	18	77

Appendix C. Mortality Data

SITE	DATE	LIVE COUNT[1]	BOX COUNT[1]	MARKET COUNT[1]	SMALL COUNT[1]	SMALL/MARK. RATIO	TOTAL MORT.(%)	RECENT MORT.(%)	MEAN SIZE (mm)[1]	MEAN SIZE (mm)[2]
BCDN	10/18/90	23	43	5	18	3.6	65	26	66	70
BCDN	10/22/91	74	68	3	71	23.7	48	6	46	58
BNMP	10/28/90	64	1	60	4	0.1	2	0	0	107
BNMP	10/28/91	43	2	43	0	0.0	4	0	0	94
BNSP	10/23/90	54	2	49	5	0.1	4	2	72	62
BNSP	10/27/91	54	2	49	5	0.1	4	2	82	100
CHBR	10/22/90	105	5	97	8	0.1	4	2	74	84
CHBR	10/25/91	188	25	113	75	0.7	12	2	82	103
CHOF	10/22/90	113	9	79	34	0.4	7	2	74	81
CHOF	10/25/91	187	5	68	119	1.8	3	0	67	88
CRCP	10/16/90	17	2	8	9	1.1	10	0	0	127
CRCP	10/21/91	42	1	22	20	0.9	2	0	0	52
CRLI	10/17/90	58	5	49	9	0.2	8	5	79	77
CRLI	10/21/91	62	50	23	39	1.7	45	13	76	88
CROS	10/17/90	216	5	94	122	1.3	2	0	77	69
CROS	10/18/91	317	8	119	198	1.7	2	1	64	66
CRRO	10/18/90	80	13	54	26	0.5	14	7	80	82
CRRO	10/22/91	128	63	37	91	2.5	33	6	60	73
CRSH	10/17/90	115	14	73	42	0.6	11	6	87	87
CRSH	10/18/91	36	106	19	17	0.9	76	18	78	86
CRTW	10/16/90	122	55	80	42	0.5	31	15	76	79
CRTW	10/21/91	188	101	62	126	2.0	35	6	57	73
EBBU	10/22/90	35	22	27	8	0.3	39	12	82	87
EBBU	10/24/91	18	20	6	12	2.0	53	5	57	84
EBHN	10/24/90	92	1	78	14	0.2	1	0	0	92
EBHN	10/23/91	70	5	48	22	0.5	7	4	109	104
EBPI	10/19/90	77	6	64	13	0.2	7	0	0	90
EBPI	10/24/91	61	46	42	19	0.5	43	5	62	88
EBWG	10/19/90	61	9	39	22	0.6	13	0	0	82
EBWG	10/23/91	123	3	62	61	1.0	2	1	92	94
FBCI	11/05/90	37	3	10	27	2.7	8	3	102	89
FBCI	11/12/91	69	14	34	35	1.0	17	4	84	77
FBGC	10/08/90	70	5	24	46	1.9	7	0	0	93
FBGC	11/12/91	101	31	53	48	0.9	24	10	77	80
HCEP	10/18/90	34	22	29	5	0.2	39	8	100	97
HCEP	10/22/91	48	28	10	38	3.8	37	6	55	77
HOHO	10/06/90	86	22	7	79	11.3	20	4	73	71
HOHO	11/13/91	127	70	20	107	5.3	36	7	64	68
HRNO	10/06/90	77	26	8	69	8.6	25	12	67	65
HRNO	11/13/91	53	49	10	43	4.3	48	13	62	71

SITE	DATE	LIVE COUNT	BOX COUNT	MARKET COUNT	SMALL COUNT	SMALL/MARK. RATIO	TOTAL MORT.(%)	RECENT MORT.(%)	MEAN SIZE (mm)[1]	MEAN SIZE (mm)[2]
HRWI	11/09/90	90	16	7	83	11.9	15	7	64	62
HRWI	11/13/91	105	24	10	95	9.5	19	4	63	69
LCCA	10/15/90	37	62	15	22	1.5	63	21	76	79
LCCA	10/16/91	202	70	13	189	14.5	26	6	50	67
LCRP	10/18/90	161	49	28	133	4.8	23	14	65	67
LCRP	10/15/91	101	116	12	89	7.4	54	27	61	68
MADP	11/14/91	49	59	7	42	6.0	55	12	65	63
MAGE	10/09/90	32	9	10	22	2.2	22	0	0	69
MAGE	11/14/91	17	16	10	7	0.7	48	0	0	77
MESR	10/16/90	270	5	137	133	1.0	2	0	72	74
MESR	10/21/91	242	23	143	99	0.7	9	1	82	75
MRAS	10/18/90	92	43	76	16	0.2	32	11	98	92
MRAS	10/24/91	55	101	51	4	0.1	65	8	103	97
MRBI	10/22/90	74	10	63	11	0.2	12	5	96	96
MRBI	10/24/91	44	45	34	10	0.3	51	2	142	110
MRLP	10/18/90	62	8	61	1	0.0	11	3	102	100
MRLP	10/24/91	25	28	25	0	0.0	53	0	0	114
MRTU	10/22/90	78	52	33	45	1.4	40	19	71	69
MRTU	10/24/91	49	51	30	19	0.6	51	11	81	76
NRMG	10/08/90	15	3	6	9	1.5	17	6	62	77
NRMG	11/12/91	64	5	17	47	2.8	7	4	79	80
NRWE	10/08/90	147	8	67	80	1.2	5	0	0	66
NRWE	11/12/91	197	10	54	143	2.6	5	2	59	72
NRWS	10/08/90	161	12	38	123	3.2	7	2	55	64
NRWS	11/12/91	80	33	58	22	0.4	29	4	65	78
POSH	10/18/90	51	3	42	9	0.2	6	0	0	72
POSH	10/23/91	49	30	33	16	0.5	38	2	122	100
PRBS	10/30/90	47	29	34	13	0.4	38	11	90	91
PRBS	11/06/91	42	37	30	12	0.4	47	9	91	90
PRBW	10/30/90	68	9	64	4	0.1	12	3	92	95
PRBW	11/06/91	38	48	33	5	0.2	56	14	97	95
PRCH	11/01/90	63	12	6	57	9.5	16	9	54	60
PRCH	11/04/91	84	33	18	66	3.7	28	8	68	63
PRLC	10/30/90	106	6	85	21	0.2	5	0	0	79
PRLC	11/05/91	63	5	50	13	0.3	7	0	0	84
PRDC	10/30/90	39	5	35	4	0.1	11	5	97	95
PRDC	11/06/91	24	10	22	2	0.1	29	0	0	102
PRRP	10/30/90	18	31	13	5	0.4	63	10	100	90
PRRP	11/06/91	20	8	10	10	1.0	29	0	0	94
PSGU	11/15/90	27	4	6	21	3.5	13	0	0	58
PSGU	11/18/91	30	17	0	30	0.0	36	12	68	70
PSMA	10/09/90	35	5	13	22	1.7	12	0	0	75
PSMA	11/18/91	42	19	12	30	2.5	31	0	0	79

SITE	DATE	LIVE COUNT	BOX COUNT	MARKET COUNT	SMALL COUNT	SMALL/MARK. RATIO	TOTAL MORT.(%)	RECENT MORT.(%)	MEAN SIZE (mm)[1]	MEAN SIZE (mm)[2]
PXBA	11/02/90	61	10	29	32	1.1	14	8	84	84
PXBA	11/08/91	42	39	23	19	0.8	48	9	74	77
PXBI	11/02/90	94	31	68	26	0.4	25	11	77	79
PXBI	11/06/91	55	61	52	3	0.1	53	5	95	88
SMCC	10/29/90	154	62	49	105	2.1	29	14	64	70
SMCC	11/04/91	118	51	41	77	1.9	30	6	71	71
SMPA	10/29/90	196	117	23	173	7.5	37	21	60	61
SMPA	11/04/91	195	62	5	190	38.0	24	5	52	59
TADM	10/17/90	74	28	71	3	0.0	28	11	99	98
TADM	10/22/91	9	42	6	3	0.5	82	10	132	102
TSBC	10/08/90	309	53	26	283	10.9	15	7	60	56
TSBC	11/14/91	138	126	22	116	5.3	48	21	61	63
TSGR	11/16/90	31	10	0	31	0.0	24	0	0	76
TSGR	11/18/91	33	5	0	33	0.0	13	3	52	46
TSOW	10/09/90	292	28	22	270	12.3	9	2	61	54
TSOW	11/18/91	61	62	18	43	2.4	50	16	66	66
TSPI	10/09/90	194	42	5	189	37.8	18	10	57	55
TSPI	11/14/91	69	100	8	61	7.6	59	22	63	65
TSSS	10/08/90	43	4	7	36	5.1	8	0	0	58
TSSS	11/12/91	82	9	24	58	2.4	10	4	77	67
TSTE	11/14/90	215	13	43	172	4.0	6	0	52	52
TSTE	11/14/91	104	40	24	80	3.3	28	12	65	70
UBBH	10/24/90	60	4	47	13	0.3	6	3	97	88
UBBH	10/28/91	71	2	58	13	0.2	3	0	0	74
UBHA	10/24/90	61	1	46	15	0.3	2	0	0	107
UBHA	10/27/91	194	3	56	138	2.5	2	0	0	54
UBTS	10/24/90	42	1	39	3	0.1	2	0	0	82
UBTS	10/29/91	93	9	35	58	1.7	9	3	87	82
WRES	11/05/90	40	5	21	19	0.9	11	5	92	81
WRES	11/12/91	30	9	17	13	0.8	23	3	107	84
WRMV	11/05/90	175	4	49	126	2.6	2	0	0	71
WRMV	11/12/91	117	8	70	47	0.7	6	0	0	74
WSBU	11/01/90	224	99	20	204	10.2	31	15	62	65
WSBU	11/07/91	129	189	56	73	1.3	59	29	66	66
WSFP	11/01/90	81	9	36	45	1.2	10	1	67	76
WSFP	10/30/91	85	44	41	44	1.1	34	9	63	69
WSHI	11/01/90	186	41	61	125	2.0	18	14	73	73
WSHI	11/07/91	47	125	37	10	0.3	73	23	82	77
WSHP	10/24/90	104	3	76	28	0.4	3	0	0	89
WSHP	10/30/91	80	13	78	2	0.0	14	1	122	111
WWLA	10/31/90	79	31	68	11	0.2	28	13	82	86
WWLA	11/05/91	108	29	17	91	5.4	21	1	52	79
WWMW	10/31/90	128	3	75	53	0.7	2	0	0	70
WWMW	11/05/91	70	10	64	6	0.1	12	3	74	86

[1]Counts are numbers per 1.0 bushel of dredged material.
[2]Mean length of new boxes.
[3]Mean length of all boxes.

Appendix D. Disease and Condition Data by Site

SITE	DATE	MEAN SIZE(mm)	MEAN CONDITION	DERMO-RECTAL[1] %	INT.	SEV.	DERMO-BLOOD[2] %	INT.	SEV.	MSX-BLOOD[3] %	INT.	SEV.	CLIONA[4]	POLY.[5]
BCDN	10/18/90	82	4.1	100	4.9	4.9	100	4.1	4.1	-	-	-	47	43
BCDN	10/22/91	72	5.3	100	5.6	5.6	-	-	-	-	-	-	20	73
BNSP	10/23/90	96	4.9	7	0.1	1.0	7	0.1	1.0	-	-	-	3	10
BNSP	10/27/91	90	6.1	27	0.7	2.6	-	-	-	-	-	-	0	33
CHBR	10/22/90	92	5.0	23	0.5	2.0	20	0.4	2.0	-	-	-	0	30
CHBR	10/25/91	90	5.9	90	2.5	3.1	-	-	-	-	-	-	0	30
CHOF	10/22/90	92	5.4	17	0.2	1.0	-	-	-	-	-	-	0	53
CHOF	10/25/91	88	6.4	20	0.5	2.3	-	-	-	-	-	-	0	50
CRCP	10/16/90	81	5.2	17	0.2	1.0	-	-	-	-	-	-	0	33
CRCP	10/21/91	92	5.2	23	0.3	1.1	20	0.4	1.0	3	0.1	4.0	0	93
CRLI	10/17/90	87	5.3	90	2.3	2.6	-	-	-	-	-	-	0	23
CRLI	10/21/91	89	4.9	100	4.0	4.0	-	-	-	-	-	-	0	73
CROS	10/17/90	79	5.5	3	0.1	1.0	-	-	-	-	-	-	0	40
CROS	10/18/91	87	5.9	60	1.7	2.8	-	-	-	-	-	-	0	90
CRRO	10/22/91	86	4.4	100	4.5	4.5	-	-	-	-	-	-	13	70
CRSH	10/17/90	88	4.7	100	5.0	5.0	100	4.0	4.0	-	-	-	0	67
CRSH	10/18/91	96	4.4	100	5.7	5.7	-	-	-	-	-	-	0	50
CRTW	10/16/90	79	4.3	100	3.2	3.2	100	3.4	3.4	-	-	-	13	67
CRTW	10/21/91	89	4.8	97	3.0	3.1	93	3.0	3.3	0	0.0	0.0	13	80
EBBU	10/22/90	92	4.4	100	3.4	3.4	100	3.9	3.9	-	-	-	7	10
EBBU	10/24/91	86	5.4	100	4.0	4.0	-	-	-	-	-	-	3	73
EBHN	10/24/90	92	4.9	30	0.3	1.1	0	0.0	0.0	-	-	-	0	33
EBHN	10/23/91	89	6.5	73	2.0	2.7	-	-	-	-	-	-	0	90
EBPI	10/19/90	66	5.0	20	0.5	2.3	-	-	-	-	-	-	0	13
EBPI	10/24/91	98	5.5	97	3.6	3.8	-	-	-	-	-	-	0	70
FBGC	10/08/90	76	3.8	60	1.8	3.0	70	1.8	2.6	0	0.0	0.0	0	20
FBGC	11/12/91	78	3.7	100	3.1	3.1	-	-	-	7	0.3	4.0	0	7
HOHO	10/08/90	75	4.0	100	4.2	4.2	100	3.4	3.4	0	0.0	0.0	3	27
HOHO	11/13/91	76	3.8	100	4.0	4.0	-	-	-	17	0.5	2.8	3	70
HRNO	10/08/90	71	3.9	100	4.3	4.3	93	2.9	3.1	0	0.0	0.0	0	30
HRNO	11/13/91	76	3.5	100	3.4	3.4	-	-	-	0	0.0	0.0	3	23
LCCA	10/15/90	97	3.3	100	3.4	3.4	97	3.2	3.3	0	0.0	0.0	37	63
LCCA	10/16/91	77	3.6	100	4.4	4.4	-	-	-	-	-	-	17	37
LCRP	10/18/90	78	4.3	100	4.8	4.8	100	4.3	4.3	0	0.0	0.0	7	63
LCRP	10/15/91	74	3.6	100	4.6	4.6	-	-	-	17	0.3	2.0	0	60
MAGE	10/09/90	78	3.0	83	1.9	2.3	57	1.4	2.5	0	0.0	0.0	11	23
MAGE	11/14/91	72	4.1	93	2.9	3.2	-	-	-	7	0.2	3.5	7	43

SITE	DATE	MEAN SIZE(mm)	MEAN CONDITION	DERMO–RECTAL[1] %	INT.	SEV.	DERMO–BLOOD[2] %	INT.	SEV.	MSX–BLOOD[3] %	INT.	SEV.	CLIONA[4]	POLY.[5]
MESR	10/16/90	79	3.5	47	0.5	1.1	3	0.1	1.0	-	9.0	-	0	53
MESR	10/21/91	80	3.7	27	0.9	3.4	-	-	-	-	-	-	7	53
MRBI	10/22/90	92	4.4	83	2.8	3.4	77	1.9	2.5	-	-	-	0	23
MRBI	10/24/91	112	4.1	100	3.3	3.3	-	-	-	-	-	-	0	68
MRLP	10/18/90	105	4.8	73	2.0	2.8	67	1.7	2.6	-	-	-	0	53
MRLP	10/24/91	104	5.5	97	4.3	4.4	-	-	-	-	-	-	0	90
MRTU	10/22/90	85	3.7	100	3.8	3.8	97	3.1	3.2	0	0.0	0.0	23	40
MRTU	10/24/91	90	5.0	100	3.3	3.3	-	-	-	-	-	-	3	53
NRWS	10/08/90	80	4.0	93	2.9	3.1	47	1.2	2.5	-	-	-	0	23
NRWS	11/12/91	87	4.6	100	2.8	2.8	-	-	-	-	-	-	0	10
PRCH	11/01/90	70	4.2	97	3.4	3.6	90	3.1	3.4	-	-	-	17	40
PRCH	11/04/91	76	3.7	83	2.3	2.8	-	-	-	0	0.0	0.0	23	60
PRLC	10/30/90	89	4.7	40	0.7	1.7	0	0.0	0.0	-	-	-	0	13
PRLC	11/05/91	94	5.9	10	0.3	2.7	-	-	-	-	-	-	0	97
PRRP	10/30/90	90	4.0	97	3.8	4.0	87	3.1	3.6	-	-	-	0	20
PRRP	11/06/91	91	4.2	90	2.8	3.1	-	-	-	0	0.0	0.0	0	100
PSMA	10/09/90	76	4.2	97	3.5	3.6	97	2.9	3.0	0	0.0	0.0	0	17
PSMA	11/18/91	74	3.8	93	3.3	3.5	-	-	-	13	0.4	2.8	0	63
PXBI	11/02/90	86	5.2	97	3.4	3.5	93	2.9	3.1	-	-	-	0	63
PXBI	11/08/91	93	4.7	100	2.8	2.8	-	-	-	-	-	-	0	27
SMCC	10/29/90	84	3.5	100	4.2	4.2	97	3.6	3.7	-	-	-	20	43
SMCC	11/04/91	83	3.9	97	3.1	3.2	-	-	-	0	0.0	0.0	23	60
SMPA	10/29/90	74	3.3	93	3.3	3.5	93	3.2	3.4	-	-	-	0	40
SMPA	11/04/91	70	3.4	97	2.3	2.4	-	-	-	-	-	-	7	17
TADM	10/17/90	99	4.6	97	3.6	3.7	97	3.2	3.3	0	0.0	0.0	0	37
TADM	10/22/91	96	5.5	100	4.9	4.9	-	-	-	-	-	-	0	83
TSBC	10/08/90	71	3.7	100	2.7	2.7	100	2.8	2.8	0	0.0	0.0	0	20
TSBC	11/14/91	76	3.5	100	4.2	4.2	-	-	-	10	0.2	2.0	27	73
TSOW	10/09/90	73	4.2	57	1.1	2.0	23	0.6	2.6	0	0.0	0.0	3	43
TSOW	11/18/91	76	3.3	100	4.5	4.5	-	-	-	13	0.4	3.3	37	13
TSPI	10/09/90	72	3.8	94	2.7	2.9	93	3.2	3.4	3	0.1	1.0	3	3
TSPI	11/14/91	72	3.5	100	3.9	3.9	-	-	-	17	0.5	3.0	27	10
TSSS	10/08/90	72	3.6	23	0.3	1.4	3	0.1	1.0	10	0.3	3.0	7	7
TSSS	11/12/91	77	3.7	60	1.2	2.0	-	-	-	20	0.5	2.5	0	7
UBHA	10/24/90	85	4.8	80	0.0	0.0	3	0.1	1.0	-	-	-	0	13
UBHA	10/27/91	103	5.8	27	0.8	3.1	-	-	-	-	-	-	0	53
WSBU	11/01/90	76	3.9	100	4.0	4.0	93	2.9	3.1	-	-	-	7	37
WSBU	11/07/91	79	4.3	100	4.0	4.0	-	-	-	0	0.0	0.0	7	90

		MEAN	MEAN	DERMO—RECTAL[1]			DERMO—BLOOD[2]			MSX—BLOOD[3]				
SITE	DATE	SIZE(mm)	CONDITION	%	INT.	SEV.	%	INT.	SEV.	%	INT.	SEV.	*CLIONA*[4]	*POLY.*[5]
WSFP	11/01/90	80	5.1	30	0.8	2.6	27	0.6	2.4	-	-	-	0	70
WSFP	10/30/91	80	5.4	97	2.6	2.7	-	-	-	-	-	-	0	57
WSHI	11/01/90	78	4.9	90	3.0	3.5	80	2.4	3.0	-	-	-	7	30
WSHI	11/07/91	80	3.5	97	4.5	4.6	-	-	-	0	0.0	0.0	23	87
WSHP	10/24/90	96	4.9	20	0.5	2.3	7	0.2	3.5	-	-	-	0	23
WSHP	10/30/91	97	6.4	47	1.1	2.3	-	-	-	-	-	-	0	53
WWLA	10/31/90	89	4.8	97	3.6	3.7	97	3.2	3.4	-	-	-	0	43
WWLA	11/05/91	92	5.6	97	2.8	2.9	-	-	-	-	-	-	3	13
WWMW	0/31/90	82	5.5	0	0.0	0.0	0	0.0	0.0	-	-	-	0	50
WWMW	1/05/91	87	5.6	80	2.0	2.5	-	-	-	-	-	-	0	33

[1]*Perkinsus marinus* diagnosed by rectal thioglycollate culture; % = prevalence (% of oysters infected); int. = intensity index (see text); sev. = severity index (see text).
[2]*P. marinus* diagnosed by hemolymph thioglycollate culture; indices as above.
[3]*Haplosporidium nelsoni* diagnosed by rapid hemolymph method; indices as above.
[4]*Cliona* sp. (boring sponge); % of oysters infected.
[5]*Polydora websteri* (boring polychaete); % of oysters infected.

FOR FURTHER INFORMATION REGARDING THIS REPORT, PLEASE CALL 410-974-3782.